



AN OVERVIEW OF AUTOMOBILE STARTING SYSTEM FAULTS AND FAULT DIAGNOSIS METHODS

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ABSTRACT

Starter motor converts electrical energy through a battery into mechanical rotating energy. These motors work under heavy load. They produce big power in a short time and in a small volume. If the starter motor fault occurred, the vehicle cannot be run, especially in emergency vehicles (ambulance, fire engine, etc.). Starter motor conveys its rotating energy with a pinion to the flywheel. For initiating internal combustion engine, the rotating moment of starter motors should be requested being greater. The starter motor must be rotating the flywheel at a minimum starting speed. It must also continue support rotation during initial combustion to maintain momentum until the engine can sustain operation. The starter motor turns for approximately 1s during each starting attempt. In each attempt the starter motor gear bounces out and meshes with the flywheel attached to the engine crankshaft. During the compression cycle of each cylinder, the starter motor torque is high, resulting in higher force on the starter gear teeth. Because of the lack of over current protection, the traditional starter control through solenoid easily causes short circuit and bums out starter. So the starter motor and its components are subjected to either mechanical fault like wear, fractures of moving parts or electrical faults like short interrupted circuit and contact resistance increase etc. This paper focuses on causes for various faults and different fault diagnosis methods and also various developments in starter motor fault control are reviewed in detail. The need of electronic control unit based starting system with some of the safety features and online monitoring system for indicating state of charge of battery is also discussed.

Keywords: starter motor, faults, solenoid, pinion, flywheel, pitting, electronic control unit.

INTRODUCTION

Engine start is the initial phase, and a very crucial phase in the operation of automotive engines. The quality of engine start influences emission and also the drivability of the vehicle. The starter motor plays a vital role in this short transient period. The main function of the starter system is to supply cranking torque to the crankshaft of the I.C. engine until a sustainable RPM is achieved due to consecutive robust engine combustion events. The torque generated by the starter motor is amplified through two or three stages of gear reduction so as to be capable of cranking the engine shaft from zero to around 200 RPM. A planetary gear-train is used to amplify the torque generated.

The cranking torque provided by the starter motor is a linear or quadratic function (depending on the stator winding configuration) of the current flowing through the rotor winding of the starter motor [1].

If a fault occurs with the starter motor, the ICE cannot be run. Especially in emergency vehicles (such as ambulance, fire engine, etc), starter motor faults causes any other faults.

Larger size engine will have high inertia at the flywheel and crank shaft. It needs starter motor with higher torque for starting the engine. When high torque motor was used, it is needed to be engaged the pinion with

the flywheel without any damage to both flywheel and pinion and then it has to develop high torque for starting the engine. Pinion is fixed on the armature shaft with an over running clutch. This over running clutch which has a slipping torque of about 3 times lock torque of starter to avoid damage to pinion and also protects armature running at high speeds, over load and transmits high torque to pinion.

In order to protect the starter system from damage due to high (transient) engine RPM, a roller one-way clutch (OWC) is introduced. In older or heavy-duty applications, a conventional gear reduction scheme may be adopted instead of a planetary gear-train. As high density magnets are readily available today, the Permanent Magnet motor is more common. It makes the starter system compact with very high torque capability [1].

In the coming years, the need for electrical energy in the vehicle will rise at an ever faster pace. The increasing demand for electrical energy stems from the large amount of electrical equipment which has become an integral part of every modern-day vehicle. This stems from the ECUs for electronic systems, and from all the safety, comfort and convenience electronics and their components. The starter motor must at all times be ready to crank the engine, and during the course of its life must successfully complete thousands of starting operations.



Taking a passenger car which is mainly operated in town traffic, this can equate to about 2000 engine starts per year for an average annual mileage of 15,000 km (10,000 miles) [2-3] while the latest starters and alternators provide improved power generation capacity, they are also smaller, lighter and quieter in order to improve fuel consumption, help reduce CO₂ and improve cabin comfort.

It is very difficult to use the starter motor effectively due to malfunctioning of solenoid switch because of its damaged contact points (pitting) due to arcing and prolonged cranking. This affects the battery life, starter motor armature and pinion finally results with vehicle idle affecting actual purpose of the vehicle.

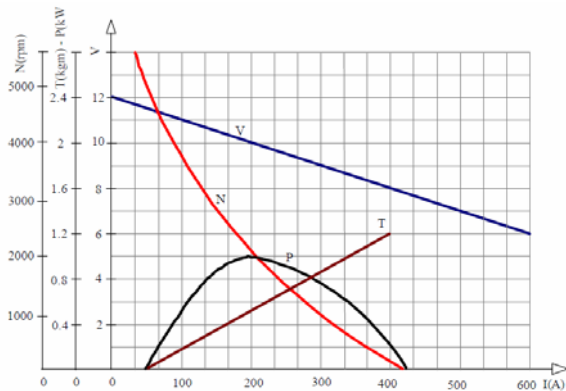


Figure-1. Performance graph of the serial wound - starter motor (1 kW/12 V).

Here the curves of revolution (rpm), power (P), torque (T), and voltage (V) are drawn subjects to the current. According to the values of variables, the status of the motor is diagnosed by the help of the performance graph. If these values are too high or too low from the desired values, it is understood that some breakdowns have already occurred or will occur soon in the motor [4].

STARTER MOTOR FAULTS

Starting of SI engines at low temperatures is easier than CI engines due to sparking systems in the combustion chamber and the fuel properties. By using the conventional lubricating oils, fuels, etc., the SI engines can easily be started by using the more volatile fuel having 10 per cent evaporation temperature at about 40°C.

Starting of diesel engine creates problems of cold starting at lowest temperatures. While studying the problem of cold starting, it was observed that four operating factors influence the diesel engine starting: (i) engine design, (ii) properties of lubricating oils, fuels and coolant, (iii) battery conditions and starter motor, and (iv) use of starting aids. Hence, cold starting of IC engines under sub-zero temperature conditions is a delicate operation. A little carelessness can damage the whole engine, but if proper precautions are taken and right type of lubricating oil, fuel, coolant, starting aid, etc. are used then a summer like start can be achieved [5].

In the case of starter motors, the load of the machine is an engine, with widely varying load torque, which is dependent on the motor condition, external environment, and multiple resonances [6]. If any fault occurred on starter motor, peak current during cranking will increase. The mostly observed faults on starter motor and starter system are; brush fault, battery fault, open circuit fault (broken connection cables, looses battery pole etc.), armature fault, field (excitation) winding' fault and short circuit fault. Because of improper starter mounting, switching or lack of maintenance etc., teeth of the starter pinion and flywheel ring gear may not mesh properly and even impact each other. Due to improper mesh or violent impact, it can induce unstable, high transient forces and torques during starting, and therefore failures or troubles such as gear teeth flake off, meshing harness, tightly meshing, armature failure, drive end housing fracture etc., are common in application after a certain period of service time [7].

As the starter gear applies force, a moment comes where contact between the starter and a flywheel gear is lost, followed by a knock when contact is reestablished. This mechanical transient translates into speed and torque transients and, subsequently, into a short transient of the stator current.

Battery Fault

Automobile engine starting requires extremely high current, in the range of 600 Amps peak for 250 ms, then a 150 A to 300A sine wave at a reasonably stable voltage for 0.5 to 3 seconds. Starter efficiency increases with higher deliverable voltage. Batteries required for these applications should be capable of operation at temperatures ranging from -208 C to 508 C [8].

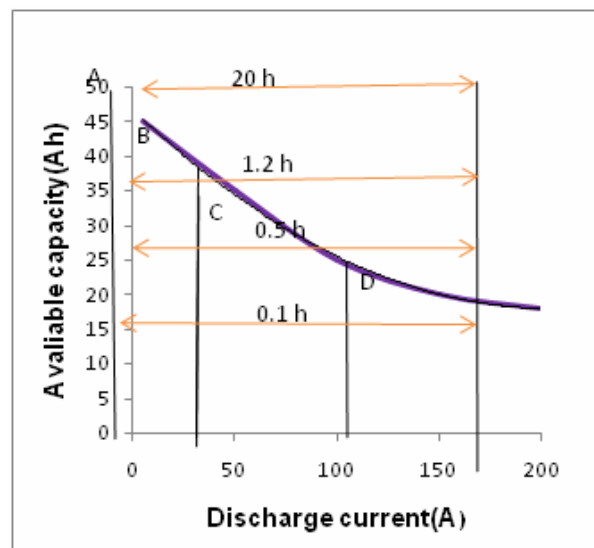


Figure-2. Battery capacity as a function of discharge current strength.

In battery fault, the battery cannot provide enough current in order to turn the flywheel. In this

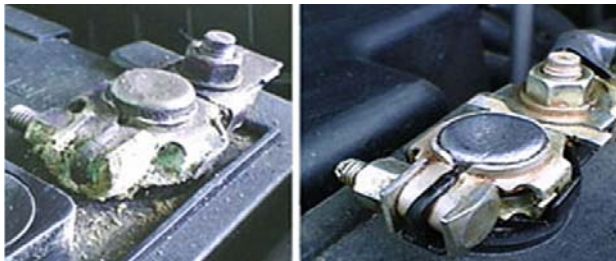


condition the battery is fully discharged or there is problem on charging system and therefore revolution of the motor will be too low.

Starter cable fault

Arcing and arc damage in an electrically energized cable is often recognized as a result of insulation failure of the cable and a possible cause for the ignition of a fire. Typically, cables routed in an automobile are protected by a combination of fusible links, circuit breakers and fuses [7]. The exception is the starter cable, which, due to the intrinsic nature of its application, is not protected by circuit breakers or fuses. Cable insulation failure can result in the energized conductor contacting the vehicle chassis, which may then result in a high-current, low resistance fault. An insulation failure of the starter cable may occur due to the following reasons:

- If the cable is routed/supported improperly, causing damage to the insulation due to shock and vibration.
- Environmental conditions may cause cable degradation.
- The starter cable may be damaged during accident.



Corroded battery terminal Good connection of cable

Figure-3. Starter motor cable fault condition.

Open circuit fault (Connection fault)

These are the cross section reduction of connection cable, a loose cable connection and the loose battery pole. The cross section of connection cable for starter motor is so essential. Decreasing the cross section of cable results in increasing the current; however, if the reduction is too much it causes the effect on revolution. In the loose connection, when the contact resistance increases, starter motor current goes up.

Solenoid contact resistance fault

The solenoid winding number N can change due to turn-to-turn winding fault, the drop of the instantaneous current i can emerge due to increased contact resistance. The draw force drops significantly in both mentioned cases. Considering the starter reliability, the starter end-of-life is reached when the draw force drops insofar it is unable to equal the passive resistance and the force of the solenoid armature pull-back spring. During the combustion engine cranking process the starter electromotor circuit is carrying current of hundreds A. If the contact resistance of the power contacts increases, the losses increase and the starter output drops. The starter

end-of-life is reached when the output is not sufficient for minimal cranking RPM of the combustion engine. Significant losses in the starter circuit which often cause the whole starting system malfunction.



Figure-4. Damaged solenoid terminal.



Figure-5. Pitting in the solenoid contacts.



Figure-6. Pitting in hold-in winding contact.

Brush fault

In the case of brush faults, the sparks occur between the starter motor and commutator and the brushes due to unsmooth contact of the brushes, dirty collector of brushes, unadjusted brush pressure springs, oval shaper collector and consumed brush life.

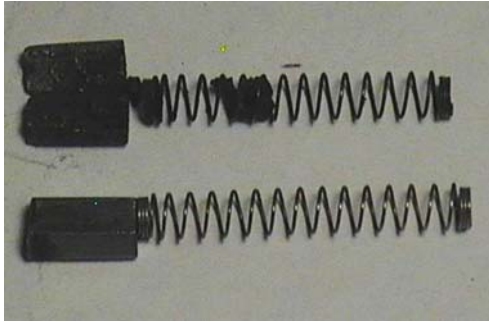


Figure-7. Brush fault in starter motor.

Especially, carbon brushes for automotive starters contain lead as an additive. The desired effect is an increase in starter performance without raising the copper to current-density ratio, which is directly correlated to the brush wear rate. However, lead dust is toxic or may cause genetic changes if incorporated, even in small quantities. In addition, lead oxidizes easily in air, which leads to dimensional and resistivity changes of the brushes over time. The role of lead in the contact has been attributed to its ability to control the film, and lowering the temperature by dissipating heat through phase transition [9].

Armature faults

When a short circuit is occurred on armature, the current drawn is getting increased. In the case of brush comes across the short circuited armature winding, the starter motor is not able to start the engine [4].



Figure-8. Starter motor armature fault.

Field winding fault

Field winding fault is either due to short circuit with the ground or the short circuit between own windings. In this case, the motor turns but there are fluctuations in torque due to the no existence of enough and smooth magnetic field. Hence the motor draws too much current subject to the largeness of the short circuit. It causes damage to the field winding.



Figure-9. Damaged field winding.

Starter motor pinion fault and drive end housing fracture

During a normal starting action, the drive pinion of a starter is turned helically and then pushed towards the engine flywheel in one continuous operation. This rapid operation makes teeth of the pinion mesh those of the flywheel ring gear successfully. But in many cases, because of improper starter mounting, switching or lack of maintenance, etc., teeth of the two gears may not mesh properly and even impact each other. Improper mesh or violent impact can induce unstable, high transient forces and torques during starting, therefore, failures or troubles such as gear teeth flake off, meshing harness, tightly meshing, clutch failure, armature failure, drive end housing fracture, etc. are common in application after a certain period of service time [10].

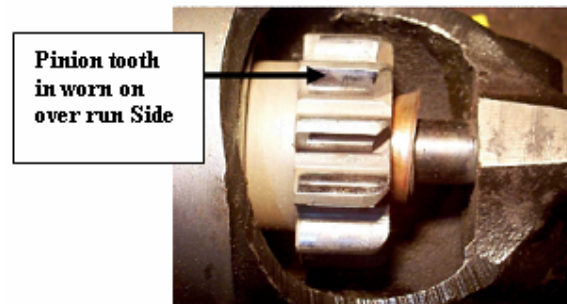


Figure-10. Failure in starter motor pinion component.

DISCUSSIONS

The above discussed faults can be detected and overcome by the following fault diagnosis methods and techniques.

Artificial neural network (ANN) based fault detection system

A fault diagnosis system for a serial wound starter motor based on multilayer feed forward artificial neural network (ANN). ANN based fault detection system has been developed for implementation on the emergency vehicles. Information of starter motor current is acquired and then it is practiced on a neural network fault diagnosis (NNFD) system. The multilayer feed forward neural network structures are used. Feed forward neural network



is trained using the back propagation algorithm. NNFD system is effective in detection of starter motor faults. NNFD system is able to diagnose the faults that can be seen in most frequencies in starter motors. By using defective starter motor current signals, the faults are classified by feed forward neural network [2].

Graphical user interface (GUI) software using learning vector quantization (LVQ) network

A graphical user interface software for real time condition monitoring and fault diagnosis of serial wound starter motors has been developed using Learning Vector Quantization (LVQ) neural network. The information of voltages and currents are acquired from the starter motor via data acquisition card and transferred to the program. Using LVQ network, the faults observed in the starter motors were successfully detected and diagnosed in real time. The GUI software makes it possible to condition monitoring and diagnosed the faults in starter motors before they occur by keeping fault records of the past occurrences [3].

Prognosis of gear faults in starter motors using time frequency distribution method

The prognosis of gear faults in starter motors using time frequency distribution method which presents future state prediction of the machine faults using Hidden Markov model with limited data. The method uses Matching Pursuit decomposition and projections of the training data on linear discriminant planes for the estimation of model parameters. This method is to ensure operation of the starter motor and the estimation of remaining useful life [11].

Prognosis method for the gear faults in dc machines uses the time-frequency features extracted from the motor current as machine health indicators and predicts the future state of fault severity using hidden Markov models (HMMs). Parameter training of HMMs generally needs huge historical data, which are often not available in the case of electrical machines. Methods use matching pursuit decomposition for estimating state-transition probabilities for computing state-dependent observation probability distributions [6]. The drawback of this method is the need of huge historical data of starter motor parts.

A fuzzy logic based fault detection system

A fuzzy logic based fault detection system has been developed for implementation on emergency vehicles. Information of the current and the voltage of a starter motor is acquired and then practiced on a fuzzy logic fault diagnosis system (FLFDS). For this purpose, a graphical user interface (GUI) software is developed by using Visual Basic 6.0 programming language. FLFDS is effective in detection of six types of starter motor faults. The proposed system can be used in a Quality Control unit of manufacturers and maintenance-repairing units [7].

Lead free carbon brushes for starter motors

Materials which could possibly replace lead would have to be cheap, conductive, and have a low melting point, a soft oxide, and a low toxic potential (Table-1). Aluminum has a low melting point, but is ruled out because of a very hard oxide. The only true candidates are tin and zinc. Tin and zinc both have high diffusion rates in copper. The diffusion rate of tin, even at ambient temperature is so high that it is impossible to put tin and copper in mechanical contact without forming an alloy within a few days. Unfortunately, these alloys have a high melting point and cannot act as a heat sink. The situation is not as critical with zinc; however, the diffusion has to be inhibited during the heat treatment [9].

Table-1. Additives to replace lead in carbon brushes [9].

Metal	Melting point (K)	Mohs hardness of metal	Mohs hardness of oxide
Copper	1356	3	3.7
Lead	600	1.5	2
Aluminum	932	2.3	9
Zinc	693	2.5	4.3
Tin	505	1.7	6.7

Automobile functions control system via Bluetooth utility

An Intelligent - Low Cost Car Control System using Bluetooth Technology enables the end-user to control different functions so that it can be controlled quickly and accurately using his own cellular phone as he/she connects it with the hand free Bluetooth device. The functions can be freely selected and each can get its own mechanism based on a microcontroller program. Up to nine separated functions can be controlled each with two switching keys, these functions include starting the engine, windows controlling in both directions, center lock, lights and alarm system, stereo system, and any other functions. The proposed system is reliable, robust and adjustable through all its designed parts to insure the maximum comfort ability of the user [12].

Starter motor peak current measuring techniques

Apparatus for measuring the ignition timing of an internal combustion engine while cranking the engine with the starter motor, and with the ignition inhibited. Starter motor current fluctuations are examined to determine the times of current peaks due to compression in individual cylinders. Means coupled to the ignition circuit determines the times of points openings. A time difference signal representing the lead or lag of the ignition relative to the starter current peaks is generated. The lead or lag is then related to the time of top dead center in terms of degrees [13].

Diagnostic apparatus, connected to probes for sensing conditions or parameters of an internal combustion engine during non-combustion cranking of the engine,



reads electrical conditions at times related to the crank angle of the engine. Electrical tests are made at times indicated by peaks and valleys in the starter current, the average of these providing load compensated indications of true electrical parameters, to eliminate effects of battery loading variations due to compression-induced variations in cranking power required [14].

The current drawn by a starter motor is derived from measuring the compression of internal combustion engine. The compression in the individual cylinders is a determining factor for the even running of the engine and thereby, for uniform stress of the crankshaft and the bearings. In the course of the life of the engine, the compression in the individual cylinders can deteriorate differently; therefore there is a need of checking the variations in compression between cylinders. If a cylinder lacks compression, a current increase occurs in the cylinder which comes next in the engine cycle, because part of the energy contained in compressed air of the preceding cylinder is missing. This missing energy must be supplied by the current source of the starter motor, which manifests itself in the current increase mentioned [15].

A measuring method for vehicles equipped with an internal combustion engine, the engine including a starter battery and a driven starter motor used when an attempt is made to start the engine, is disclosed. According to the method, a voltage across a measuring shunt inserted in a current circuit between the battery and starter motor is repeatedly measured, at a sampling rate, during each revolution of a crankshaft of the engine during the activation of the starter motor. Corresponding values of a current delivered from the starter battery to the starter motor are derived from measured voltage. Values of the current are registered in a memory of a measuring computer. The registered values are used to establish a status of the combustion engine and its starting system. A value of a derivative of a rotational speed of the combustion engine crankshaft is obtained from the registered values. The sampling rate is sufficiently high to permit obtaining the value of the derivative of the rotational speed of the combustion engine crankshaft [16].

3.8 Methods for preventing the energization of the starter motor while the engine is running.

A circuit for preventing the energization of the starter motor for an internal combustion engine while the engine is running. A first solid state switch energizes the starter relay, and also a second solid state switch. Circuitry is provided to maintain the second solid state switch energized as long as the engine is running and to prevent the first solid state switch from being reenergized as long as the second solid state switch is energized. According to one aspect of the invention time delay means is provided to insure that all rotating parts can come to a stop before the starter motor can be reenergized [22].

The circuit to control the energizing of an electric starter motor for an internal combustion engine having an electric ignition system, which prevents energizing said starter motor while the internal combustion engine is

running. The electric starter motor system comprises two electric circuits, one for starting the motor which may be directly or indirectly connected, and the other for controlling or cutting off the first or starting motor circuit. The first circuit contains the conventional starter motor, current source such as a battery, and starter switch plus a normally closed cut-off switch. The other and second circuit for controlling the first and just mentioned starter motor circuit, contains the conventional ignition switch for the ignition system of the engine, plus a normally open switch closed by the vacuum from the intake of the engine when the engine starts, and a self-holding electromagnetic means such as relay or solenoid, which when energized by the closing of the vacuum switch, opens the normally closed cut-off switch in the first starter motor circuit, whereby the starter motor control circuit remains open until the other and second cut-off control circuit is broken by the opening of the ignition switch. Thus, if the engine stalls, it cannot be restarted until the ignition switch is closed and opened again [17].

In a starter control system for an engine equipped with a starter motor, starter relay, ignition switch and electronic control unit, a circuit and method whereby the ECU will deactivate the starter relay if the operator of a vehicle attempts to re-start the vehicle when the current engine speed is greater than the minimum engine running speed, under both initial starting and engine running conditions. By deactivating, the starter relay will prevent engagement of the pinion gear to the ring gear of the starter motor, potentially reducing wear on the starter motor, grinding of the pinion gear to the ring gear when engaging the gears at a high RPM, and noise to an operator of the vehicle [18].

A controller for a vehicle starter motor, the controller comprising means for applying power to the electric starter motor as a function in particular of the open or closed state of a starter switch, wherein said means include in particular Resistor Capacitor (RC) type circuit having a charging time constant that is shorter than its discharging time constant and that charges and discharges depending on whether the starter switch is closed or open, said control means also including means for preventing power being applied to the starter motor when the voltage across the terminals of the capacitor means of the RC circuit exceeds a given threshold. This control circuit also serves to control other functions such as automatically stopping the starter or indeed providing protection against surge currents or against operator error such as trying to start an engine that is already running. The control unit is either integrated within the starter, or else it is housed externally there to in a special box [19].

ECU controlled solenoid power contactor

A motor vehicle starter system includes a contactor comprising an annular cylindrical armature and a winding which actuates a movable core in axial displacement, so that the latter acts on a control rod extending through the centre of a fixed core in the form of a disc. The control rod controls axial displacements of a



movable contact, and the contactor further includes a hood having the general form of a cylindrical pot, with a skirt portion which defines housing. The movable contactor is arranged within this housing. The starter system also includes an electronic control system for the contactor, comprising a support member such as a printed circuit board, and circuit components carried by the support member. The electronic control circuit is arranged inside the contactor [20].

A device for controlling an automobile vehicle starter motor contactor having a power contact controlling the supply of power to the electric motor of the starter motor and at least one coil controlling the movement of the said contact, one of the coils of said contactor being connected between the power supply terminal at the battery voltage and the electric motor, said device including a control unit for the starter motor and a transistor controlled by said unit that controls the supply of power to the coil or coils of the contactor, wherein the control unit includes means for turning off the transistor if the voltage at a given point between the coil and the motor is not greater than a predetermined threshold at the end of a predetermined time period from the starter switch of the vehicle closing [21].

In a motor vehicle starter contactor, a control plunger controls the axial displacements of a contact plate which is arranged in a front cover of the contactor. A fixed transverse core is arranged axially in front of the contactor winding, and an electronic circuit is fitted inside the cover, between the fixed core and a partition which divides the interior of the cover into two compartments. The partition, in the form of a separating plate, has a transverse wall portion and an axial bush in which the plunger slides. The bush has a central bore which is open at the front forwardly of the transverse wall portion, and open at the rear behind the fixed core [22].

CONCLUSIONS

The above discussed faults can be overcome by use of an Electronic Control Unit (ECU) based condition monitoring and fault diagnosis of starting system for improved battery life, starter motor service life, starter reliability and safety. In addition to that some of the safety features like enhanced seat belt reminders, gear neutral position, head lamp off positions, bonnet locked condition and engine running can be checked before attempt to start the engine to avoid damage to vehicle and passengers. The ECU based starting system has potential to be used for real time condition monitoring and fault diagnosis of vehicles with the help of industrial computers to overcome unexpected vehicle idle due to starting system faults.

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REFERENCES

- [1] QiMa Rajagopalan S.S.V, Yurkovich S. and Guezennec Y.G. 2005. A high fidelity starter model for engine start simulations. American Control Conference. 7: 4423-4427.
- [2] Bayir R and Bay O.F. 2004. Serial Wound Starter Motor Faults Diagnosis Using Artificial Neural Network. IEEE International Conference, Mechatronics. pp. 194-199.
- [3] Bayir R. 2008. Condition Monitoring and Fault Diagnosis of Serial Wound Starter Motor with Learning Vector Quantization Network. Journal of Applied Sciences. pp. 3148-3156.
- [4] Omer Faruk Bay and Raif Bayir. 2011. A Fault Diagnosis of Engine Starting System Via Starter Motors Using Fuzzy Logic Algorithm. Gazi University Journal of Science. 24(3): 437-449.
- [5] Gupta R.B. 1987. Cold starting of IC Engines. Def. Sci J. 38(1), January 1998. pp. 77-85.
- [6] Syed Sajjad H. Zaidi and Selin Aviyente. 2011. Prognosis of Gear Failures in DC Starter Motors Using Hidden Markov Models. IEEE Transactions on Industrial Electronics. 58(5).
- [7] W.L. Wang. 2008. FEA-based Structure Optimization for the Drive end Housing of an Automotive Starter. IEEE International Workshop on Modeling, Simulation and Optimization. pp. 447-450.
- [8] Ram Bhardwaj and Paul Branher. 2000. Light weight engine start battery based on thin metal film technology. IEEE. pp. 323-327.
- [9] Arwed Uecker. 2003. Lead-free carbon brushes for automotive starters. Elsevier Science.
- [10] Wang W.L. 2008. FEA-based Structure Optimization for the Drive End Housing of an Automotive Starter. IEEE International Computer Society. pp. 447-450.
- [11] Syed Sajjad H. Zaidi and Selin Aviyente. 2009. Failure Prognosis of DC Starter Motors Using Hidden Markov Models.
- [12] Qusai Abu-Ein, Suleiman Abu-Ein, Sayel M. Fayyad and Ghazi Al-Marahlehand Waleed Al-Momani. 2009. Automobile Functions Control System via Bluetooth Utility. Australian Journal of Basic and Applied Sciences. 4: 3273-3282.
- [13] 1976. US patent No. 3, 968, 425. Measuring Ignition Timing Using Starter Current. pp. 1-12.



- [14] 1977. US patent No. 4, 050, 297. Measuring Electrical Parameters of an Internal Combustion Engine during Cranking. pp. 1-13.
- [15] 1979. US patent No. 4, 144, 746. Method for Determining a Measurement value Proportional to the Compression of an Internal Combustion Engine. pp. 1-8.
- [16] 1996. US patent No. 5, 585, 717. Method for Measuring Starter Motor Current to Determine Engine Status. pp. 1-5.
- [17] 1951. US patent No. 2, 560, 094. Starter Motor Control System. pp. 1-4.
- [18] 1998. US patent No. 5, 742, 137. Starter Motor Control Circuit and Method. pp.1-10.
- [19] US patent No. 6, 050, 233. Controller for a Vehicle Starter Motor. pp. 1-6.
- [20] 1997. US patent No. 5, 703, 551. Starter Contactor having an Electric Control Circuit, and a Vehicle Starter having such a Contactor. pp. 1-8.
- [21] 1999. US patent No. 6, 003, 484. Device for Controlling an Automobile Vehicle Starter Motor Contactor. pp. 1-6.
- [22] 2001. US patent No. 6, 229, 415 B1. Contactor for a Motor Vehicle Starter, having Improved Protection for an Electronic Circuit of the Contactor. pp. 1-6.