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Induction Heating Application for Glow Plugs to Obtain Flexible Heating Capability

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***Abstract*: *Glow plug is a simple method to improve diesel engine running at cold weather conditions. Diesel engine uses air compressing capability to obtain combustion. But combustion may not start or so difficult to start for first cycle to run especially for cold weather conditions. Moreover diesel engine spews out harmful gases up to warming the engine. Glow plugs reduce the harmful gases and helps engine structure to regulate running performance. Glow plug has a resistive structure to obtain high density heating before the starting the engine related to suggested duration. Induction heating is a common way to heat many commercial components and it is possible to heat any part of the material or heating deep. Induction heating uses eddy current, and hysteresis loses on the target material related to running frequency. Heating occurs on the target material and has no temperature rising on heating filament except cause of power loses. This study merges glow plug and induction heating benefits. In order to obtain efficiency heating capability and long life period, offers modification on glow plug structure too to reduce inside power loses. Thus, glow plug starts heating from the surface and inside becomes cooler than the surface. In this study, offered self resonation induction heating was run at 368KHz and two handmade induction heating coil to test. Test current is limited to 16Ampers and was obtained 600˚C temperature on the glow plug surface after 54 seconds running.*

Keywords: *glow plug, induction heating, cold start, preheating.*

1. Introduction

Diesel engine runs without ignition plug. Compression heating during the compression fires the fuel and makes piston move down. First starting for the diesel engine is called cold start and cold start is important for diesel engine. After diesel engine warm up, engine intend to increase its revolution in per time. Idle system forced the engine at low level rpm via decreasing fuel feeding. On the contrary, for cold weather conditions, diesel engine does not intend to run easily due to low compression heating [1,2]. In order to pass the cold start without fail, externally heated air released in to intake manifold. In addition to pre heated air, compression heating increases the pre heated air up to firing level and engine starts in safe. Glow plug is widely used in diesel engine for cold start [3,4].

According to engine model, glow plugs could be located different places such as near the intake manifold or directly into the cylinder. Wherever glow plug inserted, its structure generally same and based on resistive heating. Resistive heating is sample and easy method and no need to external electronics components. Fig. 1 shows glow plug structure.

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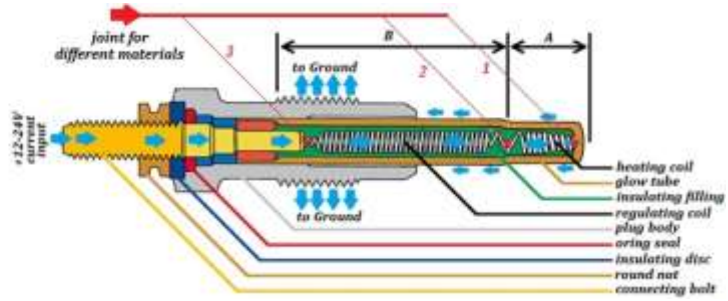


Fig. 1: Glow plug structure

Glow plugs are designed under 12 or 24 Volt DC related to accumulator voltage level. Generally connecting bolt is characterized for positive power and body is turning way for current flow. MgO is used in electrical device to isolate the live or encapsulate the devices [5,6]. Insulating MgO separates ground and positive current paths not to allow short circuit but does not ban heat transfer from core to outside. Important point is that heating coil length is shorter than regulating coil. Sector A reaches extreme temperature than B side. After the adequate temperature, regulation resistance has higher resistance to limit total current. During the target temperature, current has stable value [7,8].

Induction heating is common method to improve heating capability. More over it leads to heat sophisticated heating related to component surface [9,10]. Induction heating uses eddy and hysteresis loses to heat [11-13]. Induction heating makes heat the component without touching. Unlike resistive coils, heating starts at target components and heater is colder than the target. Eddy current induced by ac signals and generates heating related to induced side resistance. Fig. 2 shows eddy current behaviors. Magnetic field and eddy current direction is 90 degrees to each other related to right hand rules. Equ. 1 gives eddy current loses related to frequency.

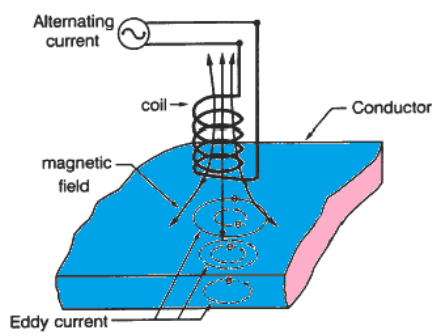


Fig. 2: Distribution of temperature on glow plug

From the Equ.1 it can be seen that square of the frequency dramatically affects the eddy current loses.

$$P_{eddy\_loss} = \frac{\pi^2 B_p^2 d^2 f^2}{6k\rho D} \tag{1}$$

Where P is the power lost per unit mass (W/kg), B_p is the peak magnetic field (T), d is the thickness of the sheet or diameter of the wire (m), f is the frequency (Hz), k is a constant, ρ is the resistivity of the material (Ω m), and D is the density of the material (kg/m^3). In case of ignoring the skin effect, electromagnetic wave fully penetrates inside the materials. In addition to eddy current hysteresis loses occurs inside the materials under AC running. For DC conditions, eddy and hysteresis losses cannot be seen.

When a magnetic material run under AC magnetization, hysteresis losses occurs inside material in addition to eddy losses [14-15]. Eddy and hysteresis losses are called core losses and these losses heats the materials. Fig. 3 shows one cycle of hysteresis curve related to a sine wave. Integration of the curve signs hysteresis losses thus, large field hysteresis curve increase the loses. Equ. 2 shows the losses related to hysteresis.

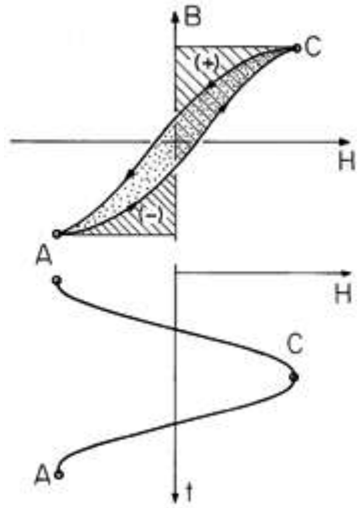


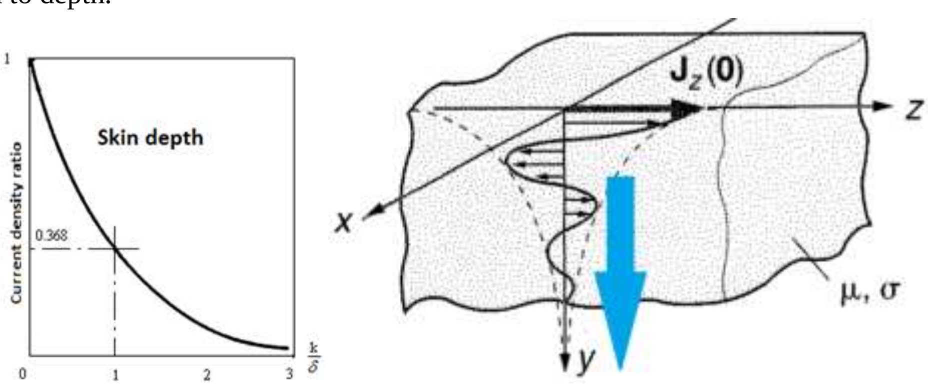
Fig. 3: Thermal Distribution Related to Distance form core to Outside

Generally, hysteresis loses is less than eddy current and most of the loses is composed by eddy losses.

$$P_{hyteresis\_loss} = k_h f B_m^n \qquad (2)$$

where k_h is a constant value of the material related to structure. B_m is the maximum flux density and n is called as Steinmetz exponent, may vary from 1.5 to 2.5 depending upon the material structure as k. n is taken 1.6 as common.

Although eddy and hysteresis loses are called core losses and determine the study inspired for the glow plug, skin effect affects the eddy losses and heating capability. Under high frequency, current does not intent flow inside conductors and wants to use surface of the materials [16-18]. Equ. 3 shows magnetic field penetrating capability related to frequency thus it signs current depth too. Fig. 4a and Fig. 4b shows skin effect moving capability related to depth.



(a) (b)

Fig. 4: (a) Current density ratio (b) Current moves to deep capability related to frequency

Depth characteristics has an exponential envelope. x magnetic field, z is current and y is penetration depth direction according to right hand rules.

$$\delta = \sqrt{\frac{\rho}{\pi f \mu_0 \mu_r}} \quad (3)$$

where δ is depth as meter. ρ is resistance of medium. f is frequency, μ_0 the relative permeability of the medium, and μ_r is a constant of material related to permeability. Related to frequency, Depth can be changed only by frequency value and it is easy way to control of the depth [19-20].

In this study, induction heated based glow plug designed, tested and compared the conventional glow plugs.

2. Materials and Methods

2.1. Proposed Circuit

In this study, self resonance induction heating circuit was used and characterized well known as Royer oscillator [21-22]. In order to obtain high power density, common tapped coil designed. In order to obtain switching the coil, MOSFETs are used. Fig. 5 shows used circuit. Circuit was designed for 24Volt vehicles and tested coil compared to 24V VSP glow plug.

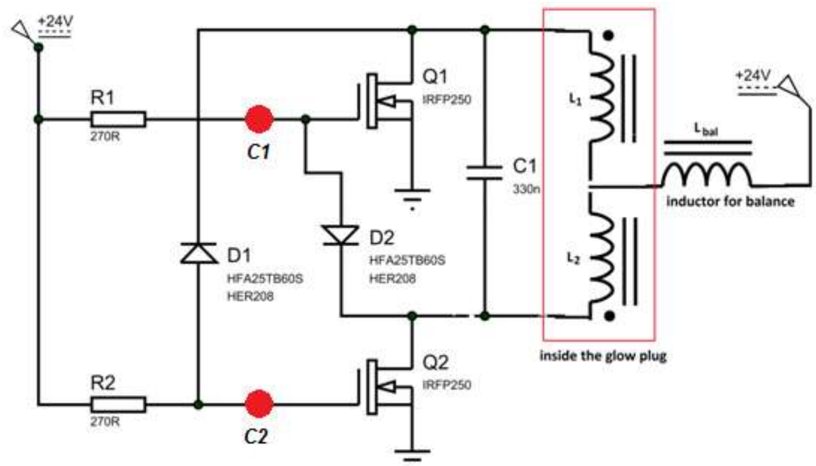


Fig. 5: Designed induction heating circuit for glow plug

C_1 and C_2 point can be arranged to stop the circuit in case of any request. Designed circuit was resonance at 368KHz. Coil for the balance used at DC side was 4mH. In this study, parallel resonation was arranged and used. The coil for induction heating has major importance to obtain resonance frequency. In this study, common tapped coil designed and measured as 2x0.21uH. Ten pieces 33nF capacitors are used to obtain resonation. Measured frequency is 368KHz at 330nF and 2x14uH coil. Power MOSFETs were screwed on to an aluminum cooler to make them cool because of the higher switching frequency.

2.2. Designed Coil for Glow Plug

In this study, common tapped coil designed to obtain high power density. In order to simulate the glow plug, rounded sheet iron based tube was used. Tube has 8.35mm diameter, 63mm length and 0.46mm thickness. Total volume is 717 mm^3. Designed coil was isolated and located inside the simulation tube.

Fig. 6: Designed induction heating circuit for glow plug

Designed coil used as glow plug. Designed circuit installed onto back side of a aluminum cooler to hold all components. Fig. 6 shows implemented circuit.

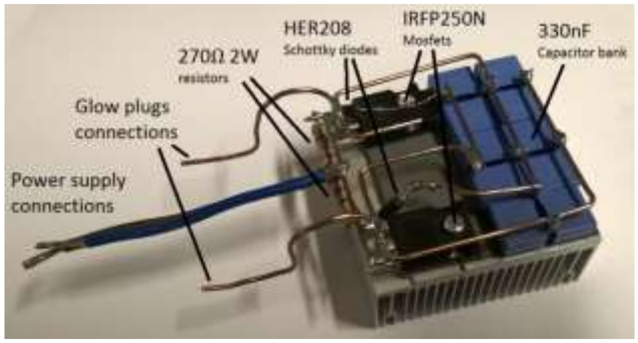


Fig. 6: The induction heating circuit for glow plug

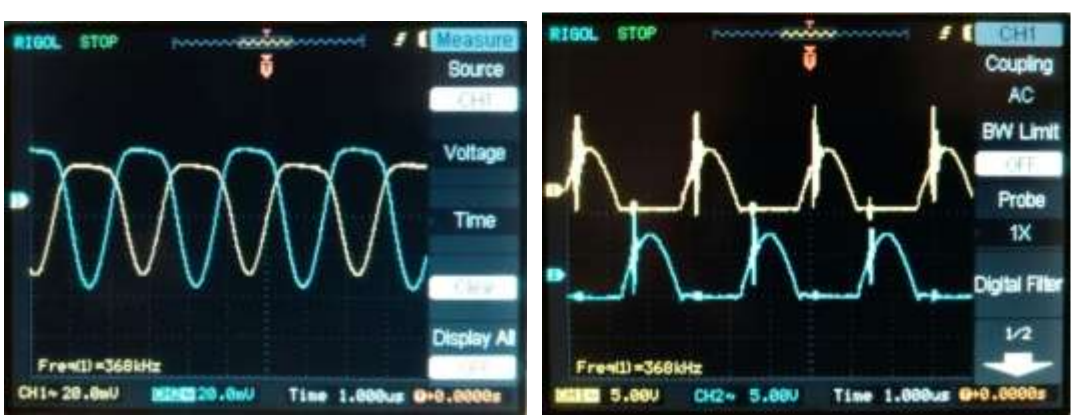
From the Fig. 6, MOSFETs, capacitor bank and cooper bars can be seen. Proposed circuit has designed to run less than 60 second to obtain targeted temperature. More over circuit can be reach curie temperature which body structure losses its permeability and natural characterized. In order to stop the circuit at right temperature degree, C1 and C2 points could be connected to ground level.

3. Experimental Results

The proposed glow plug run under 24V Dc to simulate real conditions. MOSFETs are connected to aluminum body to cool. 368KHz resonation frequency was measured. Equ. 4 shows calculation of the resonation frequency. L, inductance, is 2x2 uH. Capacitor is 330nF. Resonance frequency can be calculate using Equ. 4.

$$f_c = \frac{1}{2\pi\sqrt{LC}} \tag{4}$$

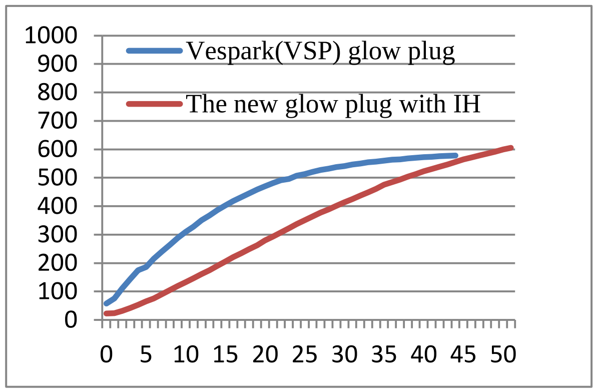
Where, C_1=330 nF and $L_1 = L_2 = 1.2$uH (1.2uH is parallel to 1.2uH). Resonation frequency was calculated as 357.74KHz and measured 368 kHz. Parallel resonation was designed. Fig. 7a shows that the signals measured at Q_1 and Q_2 gates. Fig. 7b shows MOSFETs' drains signals at heating duration.



(a) (b)

Fig. 7: (a) gate to ground signals (b) Drain to ground signals

Fig. 8a shows reddish glow plug after 54 second later running at 24Volt DC. Fig. 8b shows obtained heating characteristics with real glow plug (VSP brand) and designed glow plug. For real glow plug reaches the target temperature faster than the designed coil. But proposed coil has thicker material to heat. Thus our proposed coil relatively is faster than the real glow plug and start to heat from outside. On the contrary, conventional glow plugs based on resistive structure heat from inside to outside.



(a) (b)

Fig. 8: (a) Reddish glow plug after 54 seconds running (b) obtained heating function related to time

Designed coil has isolated from the outside to obtain high power density. Because of the home made construction, our glow plug looks thicker. But it merges benefits of the induction heating capabilities such as long life and surface heating.

4. Conclusion

In this study, induction heating based glow plug designed and tested. Self resonance is used to reduce numbers of components and to obtain self running without minimum electronics ic or device. 368KHz parallel resonance was measured for induction heating under 24V DC running. From the gates side of the MOSFETs proposed circuit can be closed or opened. The obtained heating capability is better than the conventional glow plug in spite of thicker body structure. Total body has 717mm^3 iron based rounded sheet metal and reached 600 degree Celsius after 54 second running.

The obtained results encourage us to improve the glow plug in a guide of a commercial companies to obtain marketing body structure.

5. References

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