THE LUCAS C40 DYNAMO & ITS ARMATURE.

H. Holden, March 2011.

The Dynamo as a DC generating machine was used extensively in the pre- Alternator era, from the early 1900's up to the late 1960's and early 1970's when alternators began to become standard equipment. Were Alternators truly better, or just more economical to manufacture? Similar questions have been asked of other technologies. For example, when the heavy and expensive audio output transformers were removed from audio amplifier designs in the early 1970's, was it a technical leap forward in audio amplifier equipment performance, or was that suggestion just a smokescreen for a cheaper build? In the latter case the decades of time have shown that transformer coupling to the speakers has distinct advantages, despite being more elaborate and costly. It is always a tempting proposition for a manufacturer to save money. Any new product will also be marketed to amplify the best features while ignoring the deficiencies. No complex electromechanical device is perfect in all respects. This article describes the Lucas C40 Dynamo's armature system, so the reader can also form their own conclusions about the design. This will help the reader decide whether the Dynamo was replaced because there was something wrong with it, or because it was cheaper to do it another way, or because the higher electrical system power demands in modern cars needed Alternators, or all of these things together.

As explained in another article (Alternators VS dynamos) on www.worldphaco.net , the Alternator is capable of providing higher power output at low RPM's and an overall higher output current and power carrying capacity for its physical size than a Dynamo. There are however significant losses in the rectifiers in the alternator system which a Dynamo does not have. An Alternator is a cheaper build than a Dynamo, as it does not require the elaborate and precise armature assembly of the Dynamo. The elaborate armature assembly does restrict the maximum RPM that a Dynamo can be run at and also makes for a more time consuming and expensive build for a device which converts mechanical to electrical energy.

In my opinion there is something remarkable and brilliant about Joseph Lucas's C40 dynamo as will be shown in this article. This dynamo is in fact an electromechanical masterpiece of engineering, which is perfectly appropriate to the electrical requirements of the cars at the time, especially the TR cars. The Lucas C40 would not be the ideal solution to a modern car's electrical demands. In modern cars the current and power consumption has climbed to high values due to the plethora of additional energy hungry electrical sub systems, which are generally absent in TR cars. Any electrical energy consumption in the car needs to be provided by the Dynamo or Alternator, on the average at least, as ultimately if not, the battery would discharge.

The diagram below, Figure Z, shows the equation for a loop of wire rotating in a magnetic field from my previous article on Alternators versus Dynamos. The expected waveform is sinusoidal AC and the voltage is proportional to the strength of the magnetic field B, the number of turns N of the rotating coil and the cross sectional area of the coil A. The time course is defined by the **sin** function and the angular frequency ω and the time t. The peak EMF or maximum voltage produced at any instant occurs when the rate of change of magnetic flux passing through the coil's cross sectional area is greatest. This occurs when the coil's surface area plane is on the horizontal axis and in line with the magnetic field between the North and South poles of the field coil.

In fact, in a Dynamo, the voltage waveform without commutation (mechanical rectification) would be flat topped as shown in the diagram Figure Y. This is due to the shape of the magnetic field between the curved pole pieces of the field coil's iron core in the actual Dynamo and the fact that the iron armature alters the field shape the field as shown in Figure X.

One turn loop of cross sectional area A rotating in a magnetic field B with an angular velocity of ω.

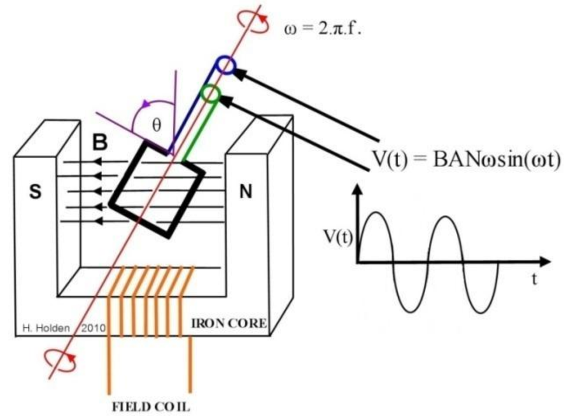


FIG. Z

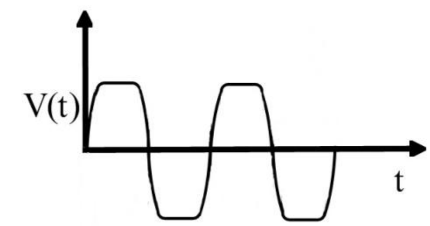


FIG. Y

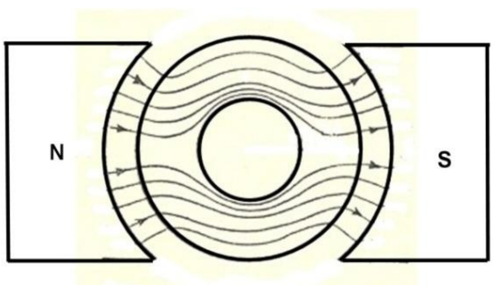


FIG. X

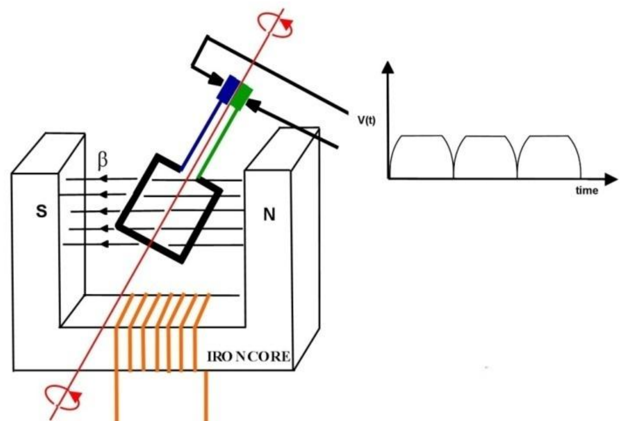


Fig.W. FIELD COIL

The flat topped waveform depicted in Figure Y is still however an alternating voltage and can only supply an alternating current. As mentioned in the previous article the commutator selects the polarity of the armature's coils to ensure rectification to DC. If there were just the single tun loop with a single split ring commutator (shown in blue and green in Figure W) the rectified voltage would appear as shown in Figure W. As can be seen this results in a single polarity or DC output however with sharp "gaps" where the voltage transiently falls to zero. These voltage transients would be unacceptable for a practical DC generator or Dynamo.

One could also reason that even with many more commutator segments and coils there would still be loss of voltage output at times. This dilemma was elegantly solved in the Dynamo by arranging the commutator to be a "make before break" switch. In this process some of the armature's coils are actually shorted out. However, as will be shown, the coils that get shorted out are not generating any significant voltage (EMF) at the time.

Figure V below, which could be a part of the C40 armature system viewed from the rear of the unit, shows two of the armature's groups of coils, one coil basically in line with the magnetic field (red) and one perpendicular to it (green). The other coils are omitted for clarity. The voltage developed is zero when the coils are near the green axis because of the zero rate of change of magnetic flux and are maximal when on the red axis when the rate of change of magnetic flux is greatest. This means it is permissible to short out the armature coils when they are near the green axis.

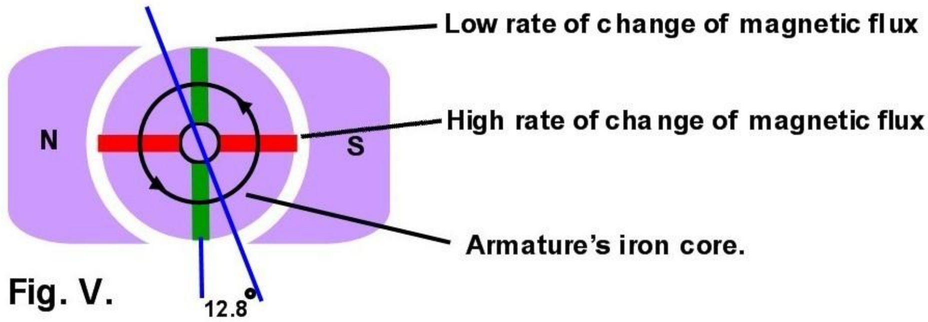


Fig. V.

In addition, current flowing in the armature's coil with loading creates another magnetic field in the armature's iron core. This combines with the field coil's magnetic field to alter it a little, causing the overall field to twist in the direction of rotation of the armature. Therefore the "neutral magnetic field" where the rate of change of magnetic flux is zero, is not in fact perpendicular to the horizontal axis between the North and South field poles, but rotated in the direction of the rotation of the armature a little, shown on the diagram as the blue line. This axis could be called the "commutation axis" and in the Lucas C40 dynamo is about 12.8 degrees along the axis or rotation.

If you inspect a C40 dynamo you will find that the brushes *appear* to be located along the horizontal axis between the field coil's pole pieces. However if you inspect the armature itself you will see that the commutator connections are rotated around "roughly" 90 degrees with respect to the armature windings they are connected to. Electrically the brushes are *nearly* on the same axis as the green coils or windings shown in figure V. Close study shows that the coils that the brushes connect to are on about a 12.8 degree offset with respect to the 90 degree position. A photo of the excellent C40 armature is shown below in Figure U. The twisted relationship is such that the commutator on the armature shaft results in the armatures coils, which are "selected" by the brushes, being 12.8 degrees advanced in the direction of the armature rotation to with respect to he vertical axis, to allow for the twisting of the magnetic field between the field coil pole pieces which is induced by the magnetic field of the armature's coil currents.

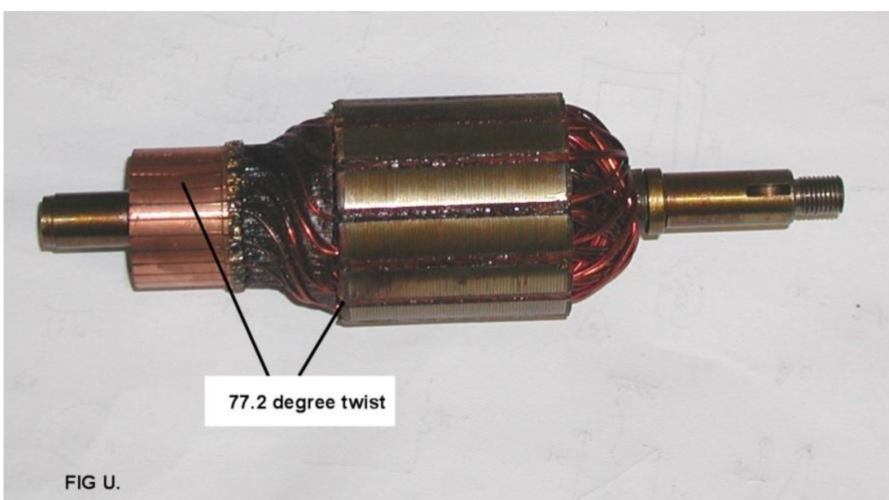
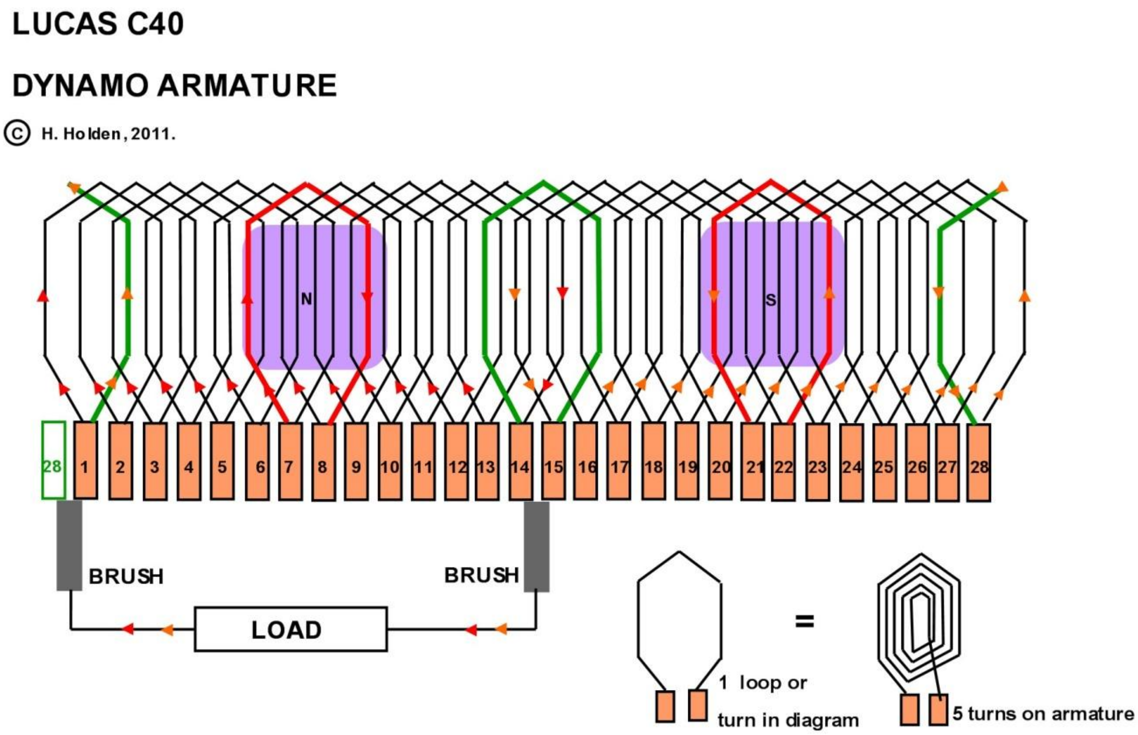


FIG U.

The wiring configuration of the armature is shown below. The output current is the sum of two currents (indicated by the red and orange arrows) which flow via all of the coils in each half of the armature which are diametrically opposed. So it is *two series circuits* (comprising a number of coils) *placed in parallel*. The diagram shows only a 1 turn loop or a one turn coil to represent each 5 turn coil that is actually on the armature, otherwise the diagram would be too cluttered. The closer to the axis of the red coil the more voltage is generated in the coil and further to the axis of the green coils (which get shorted out) the less voltage is generated. The armature has 28 copper segments and the coils link each segment to the next.



The windings are bunched into 14 slots in the ironwork of the armature's body. As each segment connects to two wires and each wire in the actual armature is associated with 5 turns of wire for each connection, then each segment is associated with 10 wires, therefore 28 segments x 10 wires = 280 wires, distributed into 14 slots in the armature's iron core. So each armature slot contains 20 wires which are around 1.25mm in diameter each. The purple rectangles in the diagram show the approximate relative positions of the field coil pole pieces in the laid out flat diagram. The brushes are shown shorting segments 28 &1 and segments 14 &15. There are times when no coils are shorted and this doesn't alter the output voltage of the dynamo as the shorted coils have little or no voltage output (EMF), but provide a continuous connection via the coil array to the more active coils in line with the magnetic field provided by the field coils.

The wiring diagram above shows the instant when the red coils are on the axis of the magnetic field of the field coils and the green coils (being shorted by the brushes) are perpendicular to the field (which is on the commutation axis). With rotation, the coil array depicted in the diagram, moves with respect to the field pole pieces and the brushes. The brushes and the field coil pole pieces have a fixed relationship. So you can imagine the coils simply changing place with each other with rotation of the armature, while the brushes maintain the same relationship with the pole pieces. This type of unfolded diagram, where the wiring is laid flat, probably gave someone the idea for a *linear motor* for a train or a linear propulsion system on tracks.

Commutation:

Just prior to being shorted out the green coils are generating little voltage (EMF) however they were carrying a load current. Then they are shorted out, then some time after that they are carrying the load current again but now in the reverse direction. Therefore the function of the commutator is to coordinate these activities so that the resultant generated DC voltage or EMF can be thought of as due to the same *number* of armature coils (but not the same coils) sitting in the same position in the field coil's magnetic field.

Figure T below shows a group of armature coils with one of the brushes initially shorting segments 15 & 16 and coil number 3.

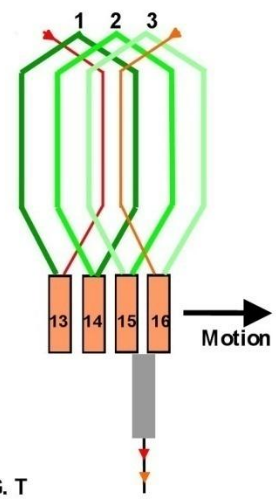


FIG. T

Consider the brush shorting segments 15 & 16. The current from one armature coil system comes from the left (the red arrow), and passes in a clockwise direction to segment 13 then via green winding 1 to segment 14, then in a clockwise direction via green winding 2 to segment 15 and then out the brush. The current from the other armature coil system passes from the right hand side (the orange arrow) to segment 16 and out the brush. Green coil 3 is shorted out. Some time later the brush is now shorting segments 14 & 15. Now coil 2 is shorted out, and there is an anticlockwise current in coil 3 and a clockwise current still in coil 1. Now the armature moves on until the brush shorts out segments 13 & 14 and coil 1. The red current path now passes directly to the brush by segment 13 and the orange current via coil 3 and coil 2 to the brush both in an anticlockwise direction.

Therefore looking at coil 2 alone, initially its current is clockwise, then it is zero (shorted) and then it is reversed (anticlockwise) during this process of commutation. Also the polarity of any coil with respect to its location between the two brushes is effective reversed after it passes by a brush. This is the function of the commutator to provide this coordinated reversal of currents as well as EMF (voltage) reversal to produce mechanical rectification and a very smooth DC output.

Efficient commutation relies on the distribution of currents via the segments into in the brush to help in the reversal of currents in the shorting coils. Nothing ever happens instantly, there is always a process. In mechanical systems the speed is limited by the mass and inertia of the moving parts. In electrical systems it is primarily limited by the inductance which opposes a change in electrical current.

The stylised diagram of Figure 1 below shows stretched commutator segments in the brownish- orange colour and the brush in light grey. The armature windings connected across these segments are represented by the inductors L1

& L2. Two 10 amp currents, from each half of the armature's winding array, pass into the commutator and into the brush. The currents have many pathways within the commutator and brush as indicated by the green lines. The more of the surface area of the carbon brush, in contact with the copper commutator, the lower the electrical resistance and the greater the current flow in that region.

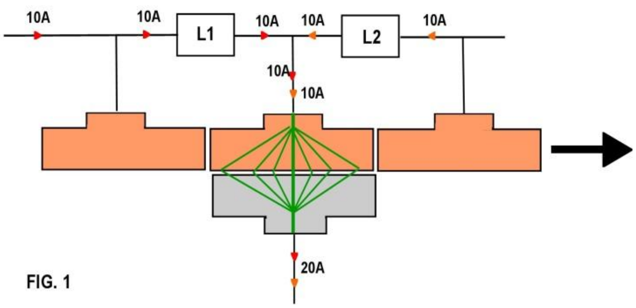


FIG. 1

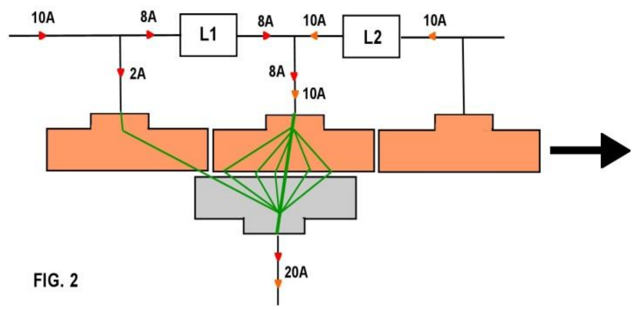


FIG. 2

Figure 2 shows a moment later after the commutator has moved to the right. Now some current, 2 amps in this example, passes from the commutator segment on the left hand side into the brush. This has the effect of reducing the current in L1 say from 10 amps to 8 amps.

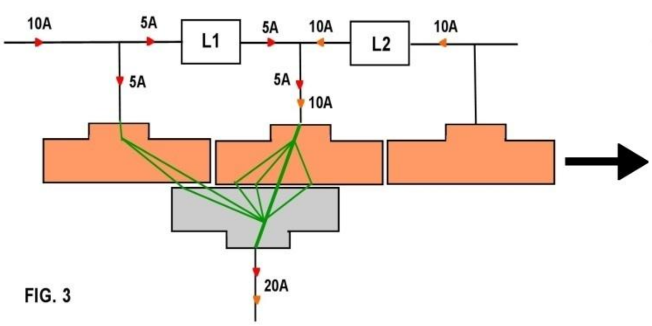


FIG. 3

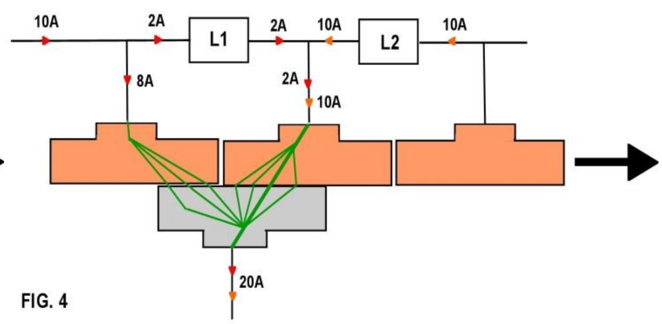


FIG. 4

Figure 3 shows the situation a moment later, the current in L1 (the armature coil in the process of being shorted out) now has its current reduced to 5 amps. All the while the output current from the brush remains steady at 20 amps. Shortly afterwards the current in L1 has reduced to 2 amps, as shown in figure 4. Moments later the current in L1 has reduced to zero and L1 is also shorted out. The currents passing through the commutator from the adjacent coils are equal at 10 amps each and pass out the brush as shown in figure 5:

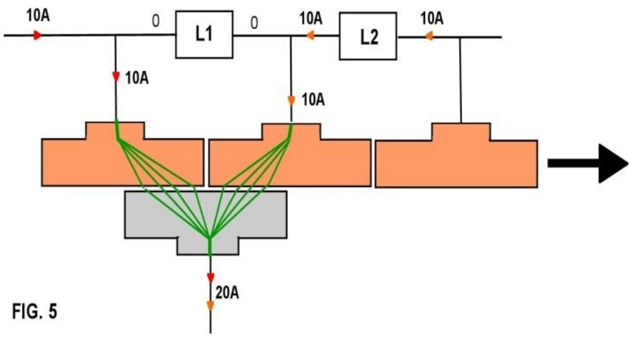


FIG. 5

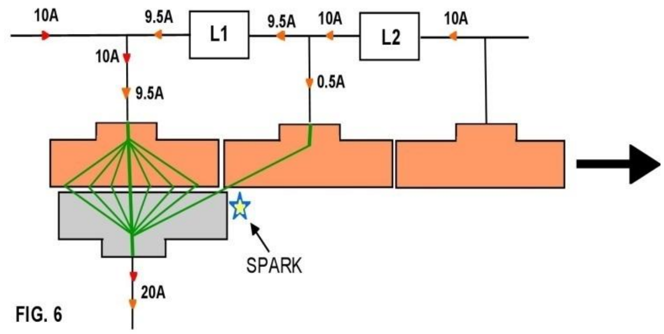


FIG. 6

As armature motion continues the processes reverse themselves and current starts to build up in L1, but this time in the reverse direction. Figure 6 shows the situation where the current has almost built up to the full reversed value of 10 amps, but has only reached 9.5 amps. So there is still some current flowing when the middle segment disconnects from the brush. In an attempt to maintain the current the inductance of L1 has a rapidly collapsing magnetic field and generates a voltage spike that causes a spark at the commutator as indicated in figure 6.

If commutation were "perfect" the coil L1 would have reached its fully reversed current value just as the middle commutator segment in the diagrams disconnected from the brush and there would be no spark. The reason why the current does not reach the exact reversed value is due to the self inductance of the armature coil. This is a form of electrical inertia. Any inductor opposes a change in current. It always takes some time to establish a new current in an inductor just as it always takes time to establish a new velocity for a moving mass. Carbon brushes, which have a very small DC resistance, help to reduce sparking at the commutator.

Summary:

Never underestimate the genius of the Dynamo or believe that it is out classed by the Alternator. The units are too different for direct comparison, like apples and pears. A Dynamo is a spectacular electro-mechanical machine, designed by brilliant Engineers. They relied on slide rules and hard study of the Electrical Sciences to get the job done, without the aid of modern electronic components or computer modelling, where equations buried in the software do all the hard work. The Dynamo is perfectly appropriate for the cars they were fitted to. They capture the magic of vintage car motoring. I enjoy knowing the electrical system in my TR4A is powered by such a great machine. I would recommend preserving the Lucas C40 dynamo for TR cars, especially if the electrical system is basically standard. The total output power of the C40 at maximum is around 300 watts (14V x 22A). A 50 watt sound system is easily supported in your car. In a standard TR car with headlamps on full beam and the heater motor on, then nearly the full dynamo capacity is used, but high beam setting is less likely for an extended period. The improvements to the Lucas charging system should be made at the level of the RB106 regulator box. See articles on www.worldphaco.net website for improving the reliability and performance of the RB106 regulator unit.

If there are additional power hungry items such as large fog lamp banks, electric radiator fans, 100 watt stereos and other electrical accessories, then a non standard modern alternator system might be indicated for your TR car. This will also sap your Horsepower though. For example, if you take 600 watts from your alternator (42 amps @ 14.2V), due to its 60% efficiency, your alternator would be taking about 1000 watts or about 1.3 Horsepower from your motor which you will pay for in non renewable hydrocarbon fuel and it will make your car less peppy to drive. True efficiency comes from reducing the electrical power consumption in the car to the lowest value, not from having high consumption electrical accessories and a high capacity Alternator powering them.

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