Engine Driven Power Sources

Converting mechanical energy to electrical energy for a vehicle's systems has been the task of two classes of machine for over 100 years: the alternator and the generator. Generators precede the alternator by a good many years. Both devices have one important feature in common. The conversion is accomplished by moving wires though strong magnetic fields or vice versa. The major difference between them is that alternators have a higher number of magnetic field transitions (north-south-north-south-etc.) for each power producing wire for each revolution of the shaft. Further, current carried to rotating parts in an alternator is via small brushes running on smooth slip rings. Unlike the generator, an alternator will run happily at 10,000 RPM. This high-frequency, low brush-wear combination allows gearing an alternator to run faster than generators on the same engine. This offers exemplary low-speed performance in smaller and lighter machines.

The practicality of an alternator before the 1960's was limited due to the lack of compact, high efficiency rectifiers. The first alternator installations I recall were in 6-volt taxi cabs in the early 50's. The radios they needed drew a lot of power and the alternator system could supply the necessary energy at curb idle. The rectifiers were external to the earliest machines; very impressive looking things with lots of heat dissipating fins.

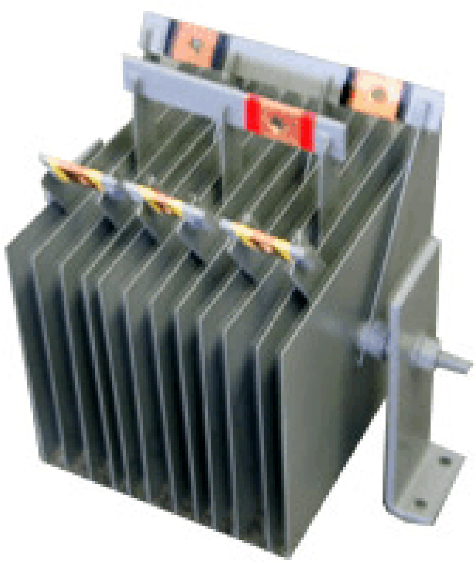

Figure 3-1. Selenium 3-Phase Power Rectifier.
Circa 1955

The regulator alone was about the size of a loaf of bread! Electrical system requirements for light airplanes were quite modest at this time; the generator was the power producing machine of choice. Few light planes had any radios at all. The landing light was the largest single load in the system. A 20-amp generator sufficed quite nicely; an alternator installation for an airplane was virtually unheard of.

The development of small but robust silicon diodes offered compact and efficient, solid state rectification of the alternator's AC output. The semiconductor age brought mobile power generation a quantum leap forward. Transistors followed a few years later to offer long lived replacements for the electro-mechanical regulators. Large volume production of alternators by the automotive industry created a wide choice sizes and suppliers of alternators adaptable to airplanes. Simultaneously, the availability of compact, low priced, sophisticated avionics packages and electrical accessories drove the lowly generator into relative extinction. Piston engine singles from Cessna feature 60-amp, 28-volt alternator systems as standard all the way down to the lowly model 152.

ALTERNATORS

The major magnetic components of the alternator are shown in Figure 3-2. The power output windings of the alternator are stationary and the field pole assembly is rotated by the power input shaft. Slip rings and brushes are needed to convey field excitation to the moving field assembly. Even the very largest aircraft alternators need only 3 amps or so of field excitation. Low current requirements along with the smooth slip rings are conducive to the very long life of an alternator brush.

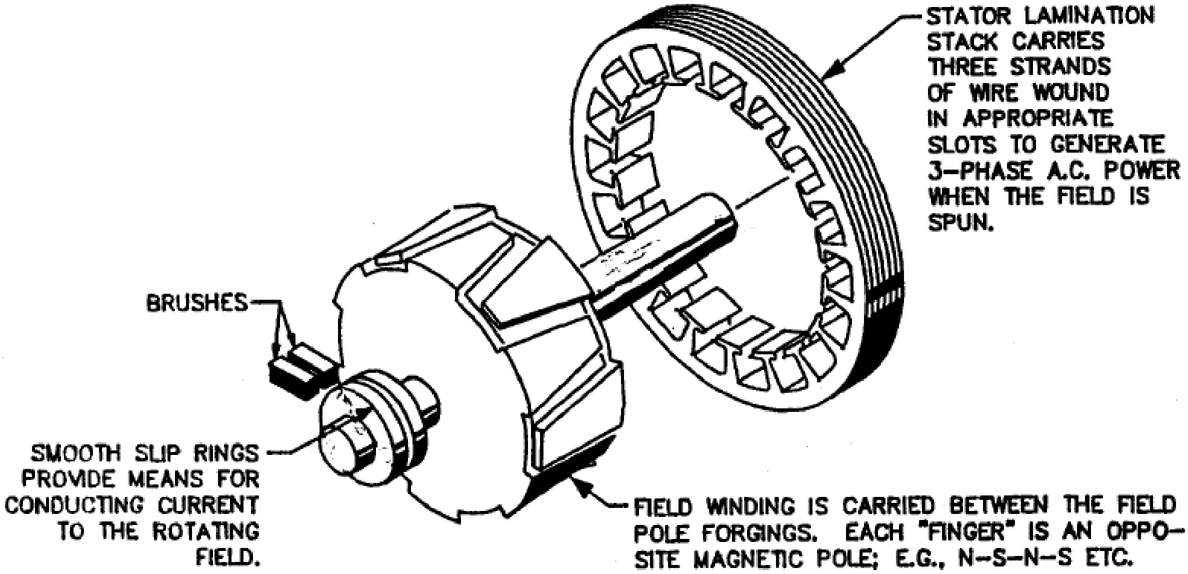

Figure 3-2. Major Components of an Alternator

The interleaved "fingers" of the alternator field assembly generate many reversals of the magnetic field around the stator windings for each revolution of the alternator shaft. This higher frequency of operation is the major factor in the superior watts per pound ratio of the alternator. There is a direct relationship of the weight per watt of power handling capability of AC devices with respect to operating frequency. For example, a 100 watt transformer for a 400 Hertz (cycles per second) aircraft power system weighs about 1/6th as much as a 100 watt transformer for a 60 Hertz house powered system. New generation automotive alternator designs have smaller drive pulleys to make them run still faster. The increase in basic operating speed (operating frequency) combined with high efficiency silicon rectifiers has produced some impressive performance in the latest generation of products.

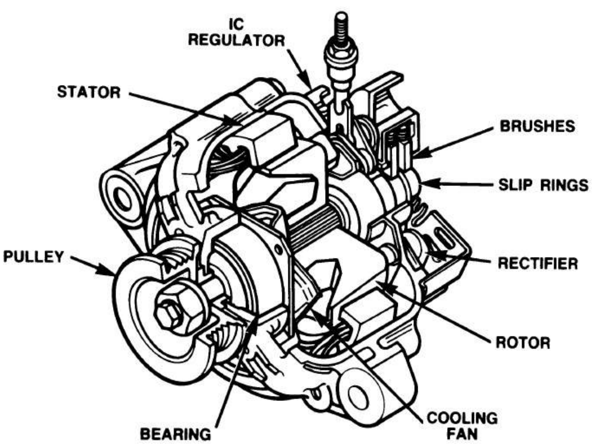

Figure 3-3. Exemplar Alternator Cutaway

Some alternators bring out extra terminals to accommodate special regulators. Others ground one of the field connections internally while others may connect it to the "BAT" or "B" terminal. Some will bring out both field terminals. Still others may be found to have nine diodes in their rectifier assemblies with the extra three used to support a special regulator or control function. It is a fairly safe bet that any alternator can be modified to work in the aircraft application with the extras either removed or ignored. If the alternator has good mechanical characteristics then the electrics can usually be made to work.

The most prevalent architecture for automotive alternators calls for built in voltage regulation. At this time, the author is not aware of any certified alternator installation that utilizes built in regulation. Design goals for aircraft power generation include:

- In airplanes, we’d like to have absolute control over the alternator by means of switches in the cockpit. This means that the system must be capable of any time, any conditions, ON/OFF control without hazard to any part of the electrical system. It’s been this way since generators were installed on day-one . . . and there are good reasons to preserve the tradition of this design goal.

- There are no regulators made that offer 10^{-9} failures per flight-hour of reliability. This tiny failure rate is what the FAA considers “failure free”. As a result, power generation systems incorporated into certified aircraft always feature some form of over-voltage protection.

The earliest adaptations of commercial-off-the-shelf (COTS) alternators to owner built and maintained (OBAM) aircraft modified alternators to remove built int regulators and

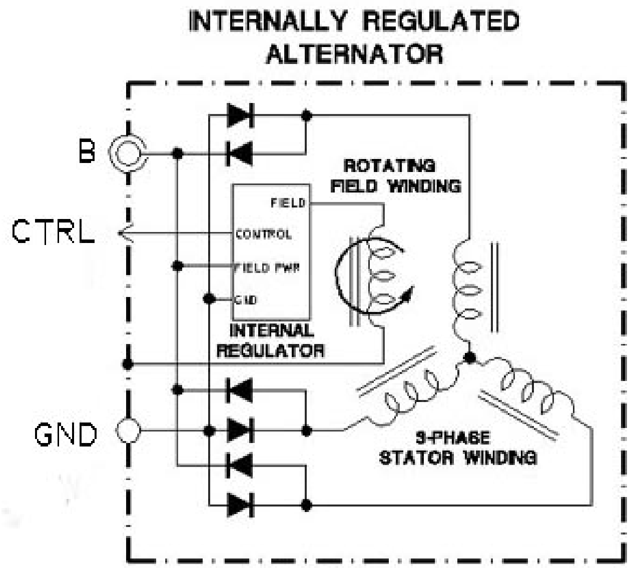

Figure 3-4. Schematic of Internally Regulated Alternator

integrate them into the airplane with external regulation and OV protection.

Figure 3-4 illustrates the electrical architecture common to internally regulated alternators. Power to excite the field comes directly from the alternator's power output terminal or "B" (Battery) terminal.

Internally regulated alternators pose a challenge to contemporary electrical system design goals. This is because there are solid state devices within the regulator's integrated control circuitry -AND- a power transistor to control field current that are vulnerable to rare but catastrophic failure that causes the alternator to operate uncontrolled at "full throttle". This "runaway" mode of operation pushes system voltage upward. Under some conditions, the voltage will quickly rise to over 100 volts. The "control" input to the alternator has no direct ability to open the field supply circuit and halt a runaway condition.

Alternators are inherently limited by magnetics in their ability to deliver current. This means that a runaway alternator will try to push the bus voltage up at some current delivery value just above the device's ratings. As I cited in Chapter 2, the ship's battery willingly, for a short time, accepts a majority of surplus energy. In the first few hundred milliseconds, a well maintained battery will keep the alternator output from pushing the bus over 18 volts or so. This gives the over voltage protection system plenty of time to shut the alternator down and protect the system from damage. OV protection systems will easily detect and react to an over voltage condition in a few tens of milliseconds.

WHAT'S THIS "AIRCRAFT" ALTERNATOR STUFF ANYHOW?

Figure 3-5 is typical of electrical architecture when alternators first hit the automotive scene.

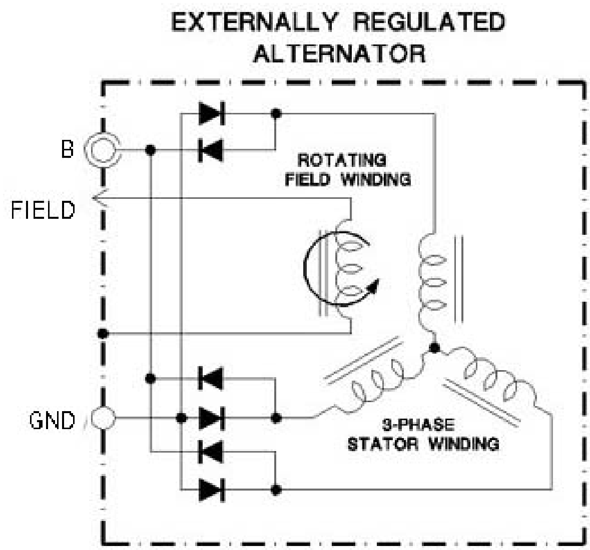

Figure 3-5. Schematic of Externally Regulated Alternator

Note that unlike the internally regulated alternator, the field supply must come from outside the alternator. In the days before OV protection, control of energy to the field was a singular responsibility of the regulator. Even before the advent of solid state regulators, there were failure modes in electro-mechanical regulators that would full-field the alternator and produce a runaway.

Unlike generators, alternators were capable of output voltages several nominal . . . delivered at the full current rating of the machine. It didn't take too many OV events before we scrambled to add independent means of interrupting field supply current when an OV condition was detected. Given that all field supply came from outside the alternator, adding OV protection in series with the supply line was a no-brainer. Your's truly developed the circuitry that was ultimately installed in thousands of single engine Cessnas before solid state regulators came with OV protection built in.

In the story of alternator evolution, solid state electronics made it practical to move voltage regulation inside the alternator. Before this juncture, there was little difference between alternators destined for use on airplanes or cars. But as soon as the regulator moved inside, we lost the ability to exercise absolute control over the alternator's field supply. This feature was contrary to traditional design goals for (1) any time, any conditions, ON/OFF control combined with (2) independent detection of an OV event and subsequent alternator shut-down. It became popular speech to separate internally and externally regulated machines into "automotive" and "aircraft" categories.

In reality, there was little difference in the two products with respect to robustness or quality of craftsmanship. In fact, alternators qualified to fly on aircraft became bogged down in bureaucratic and regulatory tar pits that essentially halted their evolution. At the same time, design, manufacturing and aftermarket services for automotive products evolved into some of the most efficient, compact and cost-effective machines for DC power generation in light aircraft.

Figure 3-6. "Aircraft" or "Automotive"?
That IS the Question.

I'll suggest that the term "aircraft alternator" has no significance except perhaps to notice the field supply current source. Further, there ARE ways that the astute system integrator can successfully install a COTS alternator right out of the car parts store.

To be sure, there are lots of choices for configuring your alternator package. Duplication of a proven installation is the $time$ saving decision for moving your project forward. There are a number of suppliers who offer alternators with or without installation kits. Before your turn your nose up at the idea of buying those funny pieces of bent-up sheet-metal, consider how much $time$ it might take you to find the right material and carve them out yourself!

INTERNAL OR EXTERNAL REGULATION?

There is no compelling reason to assert that any of the popular alternator, regulator and OV protection schemes are better or worse than others . . . assuming they were crafted with aircraft operability in mind. They need to meet design goals for performance, controllability, and compatibility with other systems. Electro-Magnetic Compatibility (EMC) looks at keeping noise emissions from your alternator system below those levels which pose problems for other systems along with immunity from radio transmitters in your airplane.

Understand that the 'Connection promotes system architectures and operating philosophies that have evolved from an artful application of good science, simple ideas and validated by a long history of experience.

All of Z-Figures at the back of this book go to meeting the design goals cited earlier. There's a body of thought in the OBAM aircraft community suggesting that pilots can do without an ability to shut down an alternator at will. Some folks have also suggested that independent and dominant OV protection is unnecessary with certain COTS alternators. Their failure modes are sufficiently benign . . . or their designs sufficiently reliable to make concerns for OV protection moot. Design goals for your airplane are your choice. Please go with the fabrication and operating philosophy that gives you the most comfort. I can confidently assert that a faith in the relative goodness of a particular brand of alternator is ill advised. More on this later.

It is entirely possible and perhaps even practical to convert an internally regulated alternator to externally regulated. The variables for accomplishing a conversion on so many otherwise suitable brands of alternator are too numerous to attempt useful coverage in these pages. There are a number of articles on the Internet that describe successful external regulation modifications for specific alternators.

The goal is simple. Deduce a means by which one of the existing brushes can be grounded to alternator frame and the other brought out on a lead that bypasses the built in regulator. This can usually be accomplished with a little study of the proposed alternator's internals.

There are alternatives to such modification that still meet traditional design goals illustrated in the Z-Figures.

FITTING THE ALTERNATOR TO AN AIRPLANE

Successful adaptation of any alternator to airplanes requires attention to (1) electrical and (2) mechanical interfaces. The mechanical interface is pretty straight-forward. The most robust alternator support calls for mounting ears on BOTH end-bells. The alternator in Figure 3-6 is a good example. The bolt that passes through these holes should also pass through two ears on an engine mounted bracket. Before you make purchase decisions, take a look at the popular options on other folks airplanes. All of the hardware used to attach an alternator to your airplane should be STEEL. No aluminum . . . I don't care how pretty that bright anodized attached bracket is. I've seen and participated in too many mechanical integration problems where even steel brackets were breaking . . . aluminum just isn't an option.

Figure 3-7. Exemplar Lycoming Boss-Mount Alternator Bracket - BEEFY!

One thing in your favor for bolting modern alternators to airplanes is the small diameter of the machine. A long time ago, Piper negotiated what they thought was a good deal for Chrysler "pancake" alternators. The diameter of these alternators made their low speed outputs attractive . . . but the mechanical overhang moments were horrible. For many years, owner/operators of Piper single-engine airplanes were plagued with a rash of bracket failures.

The bracket in Figure 3-7 is made from 1/4" thick steel. An excellent example of adequate support for a small diameter machine like that shown in Figure 3-6. When bolting your alternator of choice to the engine, be aware of clamp up forces that tend to spread or compress the ears of either the bracket or alternator. Note that the mounting ear on the rear end bell has a split liner in the hole. This liner-spacer is designed to slide in the hole to relieve any such clamp up forces. If your alternator of choice doesn't come with the slip-fit liner, then install spacers/shims between mounting bracket and alternator mounting ears to minimize if not eliminate clamp up forces as the bolt is tightened.

There's a requirement that the two pulleys line up for proper belt tracking and finally, you need a means by which belt tension can be adjusted and maintained. This is usually accomplished with some bracket or brace that engages the single ear on the alternator's front end bell.

Your alternator will need to be fitted with a pulley that matches the belt that matches your engine pulley. If you have to change the alternator pulley, the nut that holds the pulley on the shaft should be installed with an impact wrench. When picking a pulley size, be aware that some of the most successful alternator offerings to OBAM aviation feature pulleys that cruise the alternator at over 10,000 RPM! The smaller pulley and high RPM offers these attractions: (1) better support of electrical system loads at taxi speeds while rapidly recharging the battery. (2) better cowling clearance and (3) better cooling of the alternator due to increased flow through internal fans. The rationale offered most often for slowing an alternator down is to accommodate some idea about bearing or brush limits. Know that many suppliers don't find this idea compelling.

ALTERNATOR INTEGRATION WITH THE ELECTRICAL SYSTEM

Once you're satisfied with the mechanicals, the electrical integration is easy. The architecture drawings in Appendix Z pretty well cover the options for wiring up internal or externally regulated alternators. All the options offered feature positive ON/OFF control from the pilots seat and independent, dominant OV protection.

SO MANY CHOICES, SO LITTLE $TIME$

I often use the word "time" bracketed by dollar signs in my writing. I think it's important to keep track of the value of time when it comes to making choices for how your project goes together. We know that education is always expensive. There are builders who have crafted a recipe for success and are flying trouble-free systems that perform to design goals.

But if they're on the third or fourth configuration having invested much $time$ in learning how to do it, might they have been $time$ ahead by purchasing an off-the-shelf system with a track record? If you enjoy the learning process, then ignore the above. As long as you craft failure tolerant systems, it matters not whether you're flying the second or tenth iteration of an evolving design.

There are few topics of discussion in the OBAM aviation community that have demanded so great an expenditure of $time$ as the selection and operation of alternators. Much of the opinion offered arises from some bad experience by a pilot . . . frequently offered in what I call “dark and stormy night” stories. Written with enough attention (or inattention) to the reader’s lack of knowledge, such stories usually generate many concerns and precious little if any understanding. So when it comes to alternator shopping, let us assume you’re game for playing the field.

In the fall of 2008, I had the privilege of touring the research, development and manufacturing facilities of Motorcar Parts of America. What I witnessed was amazing and enlightening. I’m working on a detailed narration of that experience to be published on the website. However, this chapter would be incomplete without touching on the highlights of the story..

When it comes to purchasing any commercial off the shelf (COTS) alternator, questions usually focus on pedigree, “Is it good enough to perform well on my airplane.” Some of the most powerful discoveries from my trip went to questions like these:

- “If I want to offer a really cheap product for the purpose of attracting the low customer, what can I do to take costs out of my product?”
- “What fraction of total customers have purchase price of the product as the primary concern?”
- “How much difference is there between cost of building the bargain basement product and the best-we-know how to do?

The MPA manufacturing facility in Tijuana (Motorcar Parts of Mexico) employs 1100 folks producing 22,000 units per day (starters and alternators). For a 9-hour day, this translates to an average investment of direct + indirect labor of 27 minutes per unit. This includes receiving, sorting, warehousing by line-item, tear down, cleaning, reassembly with new wear-out-items, automated testing, warehousing by line-item, packaging in customer’s branded boxes, palleting and shipping. Hmmm . . . obviously not enough time to do a good job you say?

It takes twice as long to put one together and test it as opposed to taking it apart and cleaning. So bins of grimy cores are dropped at a tear-down-and-clean station that is sandwiched between two assembly stations. All motions for the twisting, prying and pressing of parts for disassembly and reassembly are accomplished with power tools. Time lapse from grimy-bin removal to shiny-bin replacement is about 45 minutes.

The factory is bright, clean, odorless and staffed with folks wearing street clothes with perhaps a plastic throw-away apron. One lady I saw was in tan slacks, white shirt and didn’t have a spot on her clothes anywhere. The factory was an exemplar demonstration of ***lean manufacturing*** which suggests you ***don’t do anything to a part heat does not add value***. Further, you offer your workers ***every labor/effort reducing tool available***.

The MPM shipping department loads alternators into a host of house-branded cartons, including brands of some big name original manufacturers. The whole process from incoming identification of cores to the loading of pallets on trucks is digitally aided and tracked. The average out-the-door cost of any one product wouldn’t take a family of four out for a round of Big Macs.

The next day we visited their IR&D facility in Torrance, California. This facility includes a lab that automatically exercises dozens of test articles at once and operates 24/7. The test articles are evaluated for performance and life issues. They gather and archive over 800 test-hours of data per day. There’s a constant effort to improve on performance as demonstrated by reducing the rate of return for fielded product.

In the lab we witnessed a full-load, max RPM, hot alternator load dump. As the technician removed a large fat-wire clip at the B-lead, a flash of electrical fire was so bright that attempts to video the event with my camera failed miserably. You saw the technician in the video before and after the event but only one or two solid white frames during the event. This and all MPA/MPM products are expected to shrug off this abuse 5 times in a row!

I asked the engineering director’s opinion as to the best brand of alternator. He looked quizzical and admitted that he didn’t have an opinion. The various alternators that come to his facility are simply raw material. His job was to track the quality of specific part numbers based on distributor, dealer and customer satisfaction. If any particular alternator was producing an unusual or unacceptable rate of real failure, it was his job to rectify that condition. He cited situations where perhaps a regulator on a particular OEM alternator was found lacking. These discoveries generated re-design efforts that produced a better-than-new alternator.

The significance of his explanation was quite clear. His company stocks 2800 line-items of starters and alternators. A mere 400 line-items were responsible for 80% of their business. But if they were going to be in the business, they could not limit their attention to the big movers. They needed to ***do it all or do nothing***. The logo on the incoming alternator had no particular significance with respect to their business model. They took no notice and had no interest in whether the part was coming in for it’s first or tenth rebuild cycle. After the part leaves his factory, it’s an MPA/MPM part wherein the most expensive but non-wearing raw materials were salvaged from carcass of another, essentially irrelevant brand name device.

Products from this facility have been sold in three "quality levels" with each level demanding more dollars from the customer at the counter. Rates of return for the three quality levels were noteworthy. I don't recall the exact numbers but the ratios were startling. "Lowest quality" produced the highest return rate . . . yeah, you might expect that.. The "mid quality" was about 2/3 hat of the low quality rate. "Highest quality" parts came back at about 1/3 the rate of the low quality parts.

A bit of research into these disparities showed that rates of return had more to do with skill, understanding and integrity of the installer than it did with real value of the ***same exact part***! Irrespective of the "quality level" offered over the counter, additional dollars only buys the customer a longer service policy for the same piece of hardware. This begs the question, why not offer the highest quality level only? Not only do you take in more cash you reduce the rate of return. No doubt folks have used that business model for a host of products . . . and watched the majority of prospective customers gravitate to their competitor's stores.

What might we deduce from this information about the suitability of a particular alternator for your airplane? Let us understand that quality has more to do with the last guy that worked on it than with the original manufacturer. If you're going to be successful in the after-market alternator business, you'd better figure out the most effective way to deliver the best-you-know-how-to-do.

End-to-end labor and "service contracts" are the largest driver of sale price at the counter. Quality of parts used in a re-man have little to do with the final selling price. It follows that there us no advantage in cost-cutting the bill of materials. Successful automotive re-manufacturing requires a supplier to meet expectations of a chain of stores that buys $millions$ per year in parts.

These chains cater to consumers at ***all skill levels***. It would be exceedingly foolish to sell these clients short. An unhappy customer costs you an occasional hit on one item. An unhappy distribution chain costs you your rear end! The idea that any big name re-manufacturing operation isn't delivering product equal to or better than OEM just doesn't make sense.

Consider that the OEM gets a constrained view of product performance. Virtually all OEM development activity is based on in-house testing before the design is finalized and field history for a relatively benign service environment (new cars). The re-man guys are gathering performance and service history in the rough-and-tumble world of aftermarket sales where the end user is everyone from the master mechanic to the shade-tree-do-it-yerselfer having only a pair of pliers and a hammer for tools. It seems likely that the re-manufacturing folks have a richer opportunity to apply statistical process controls to the improvement of their products. That is precisely what I believe I witnessed at MPA/MPM.

Let us suppose you crave a model of factory-new alternator. The aftermarket re-man operations are so efficient and cost-effective that even dealers will be loath to stock truly "brand new" alternators. They probably stock only big-movers as new parts, they'll cost you about 30% more and there will be fewer choices. The re-manufacturing guys are buying the most expensive but non-wearing parts at scrap prices and folding them into zero-time product at a small fraction of the price for all new parts. The factory-new guys simply cannot compete with the competent, lean, re-manufacturing business model.

Okay, suppose you're adventuresome and have elected not to buy a plug-n-play alternator. All brands of alternator offer dozens of styles with sufficient power output capability. Getting suitable attach hardware that lines up the pulleys and sets belt tension is the problem to be solved first. If you find a "kit" of mounting parts, the shape of those parts puts an immediate boundary on your choices for suitable alternators. Your field of choices drops from perhaps a few hundred line-items down to a few dozen examples of a particular alternator frame.

After that, you need to choose a product that meets design goals consistent with those cited earlier -OR- design goals suggested by others. If you choose the legacy design goals described in these pages, then the Z-Figures at the back of this book will guide your integration of either an internal or externally regulated alternator.

For reasons stated, alternative design goals are not included in these pages. However, if alternative ideas are attractive and should you discover performance pot-holes later, I'll suggest you join us on the AeroElectric-List (an email based forum hosted at Matronics.com). The membership and I will endeavor to assist you in sorting out the alternatives.

Finally, understand that most discussions about Nipon-Denso being the "better" alternator compared to say a Bosch are unsubstantiated flooby-dust. If your alternator of choice was cycled through MPA/MPM or one of it's able competitors, it's likely to be of good value irrespective of the logos molded into the castings.

ALTERNATOR FAULT ISOLATION

Alternator charging systems are stone simple to diagnose and repair . . . assuming that you have a minimal understanding of how these things go about meeting design goals.

The partial failure that does not kill the alternator dead may be subtle. I bought a car once that had an internal broken connection thrown in at no extra charge. Not having any experience with how the panel ammeter behaved with a good alternator I didn't have any reason to investigate and the degraded alternator performance became my 'norm'. It was months later, in the winter, when I noticed that the battery ammeter would go into slight discharge with the headlights and blower motor on with heavier discharge when I hit the brake pedal. Obviously the alternator was incapable of carrying the peak running loads of the car even though battery voltage was being properly maintained under conditions of light loading.

I replaced the alternator and the battery ammeter really came alive after engine start compared to the performance of the old alternator. I tore the old alternator down and found a cracked lead on a rectifier assembly which reduced the 45 amp alternator to little more than a 20 amp device. Some noises in my amateur radio equipment went away too! The rectified DC from a fully functional alternator is quite smooth compared to the one with a broken lead. Moral of the story: "Be sensitive to ***changes*** in the way your system behaves and ***investigate.***"

Investigation is the key word here. You should know what part needs replacing before you ever touch the airplane with a wrench. Too many of our brothers in both TC and OBAM aviation troubleshoot by takings stuff of the airplane for bench testing or worse, playing “swaptronics”. Swaptronics is a game you play by putting in new stuff on the airplane until the system comes back alive.

The safest way to check for possible degraded alternator performance is to remove the thing and run it on a test bench. It is a lot of trouble but test benches don't remove pieces - well . . . ***big*** pieces of your body. If you do test the alternator in place on your airplane, get assistance at the controls and make test set up changes with the engine stopped. Here are some things you can do.

OUTPUT CURRENT TEST

You can test your alternator’s output capability with the assistance a battery load tester described in the chapter on batteries. Connect the load tester right to your ship’s battery under conditions where you can run the engine. With the load tester set to zero, start the engine and advance RPM to something above the minimum RPM for sustained flight. This might be 2000 RPM on the average Lycoming installation.

Minimize loads on the system to the lowest possible value. This might be assisted by pulling fuses or breakers for those devices that cannot be shut off. If you have an alternator load-meter installed, you don’t need to shed loads.

Watch the bus voltage while you advance the load-tester’s current draw until . . .

(1) the ship’s alternator indicates 100% of design load meaning that the alternator is healthy and capable of rated output or . . .

(2) the bus voltage falls by say 0.5 volts whereupon you read the load current displayed on the load tester. Read the load value of current from the load-tester and add to it, any ship’s loads you could not shed before the test. The total of these values should be equal to or greater than the output rating of your alternator.

If the alternator is crippled by loss of one or more diodes, you won’t even get close to rated output. So we’re looking for gross inability to support rated load and not looking to reject an alternator that appears to be say 10 or even 20% short of rated capability.

This test works for both internally and externally regulated alternators. It is remotely possible that inability to shoulder full load is a regulator problem. We’ll touch on that in more detail in the next chapter

DIVIDE AND CONQUER

If your alternator is internally regulated and the bus voltage doesn’t come up when the alternator is turned ON, then simple voltage checks will show . . .

(1) There is voltage at the alternator CONTROL pin that commands the alternator to come alive and . . .

(2) The voltage drop between the input and output of the b-lead contactor is less than 0.1 volts indicating that the contactor is closed.

If those two conditions are met, then it’s time to put the wrench to the alternator for removal and repair.

If your alternator is externally regulated, you need to know if the fault is with the (1) alternator or (2) regulator, OV protection and associated wiring. Figure 3-8 illustrates a low cost test tool for the externally regulated alternator.

It’s fabricated from a generic “ford” regulator, a few pieces of wire and terminal appropriate to the connections on your alternator. You disconnect the alternator field wire but leave the b-lead connected. Install this temporary regulator by

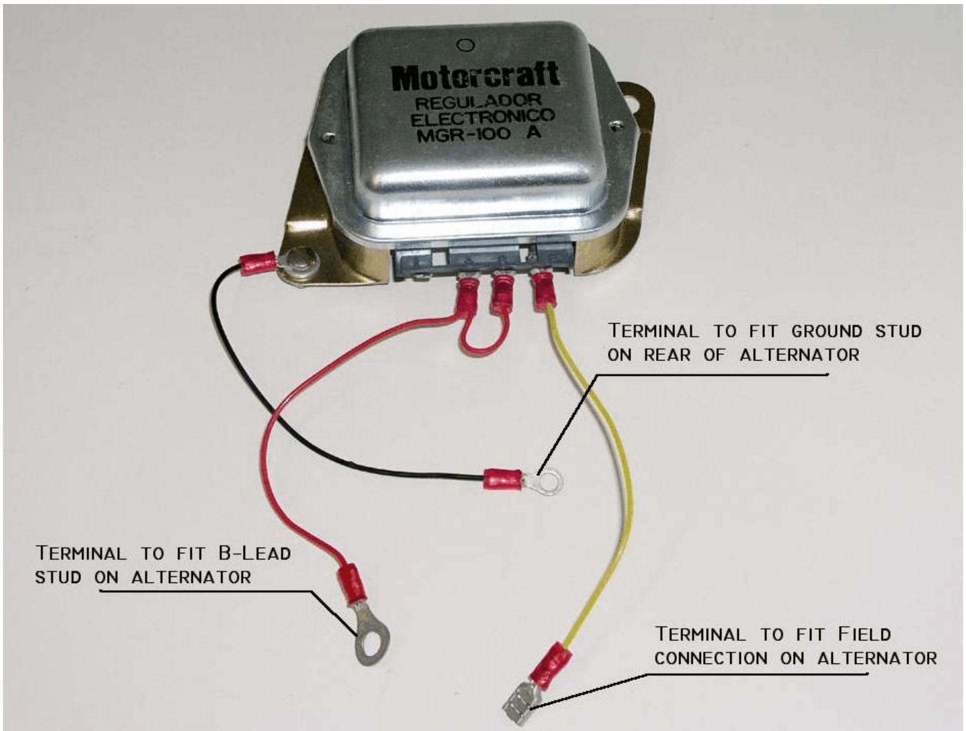

Figure 3-8. Externally Regulated Alternator Test Fixture.

attaching wires to the b-lead, field terminal and alternator case ground as cited in the photo.

Start the engine and advance throttle to 2,000 RPM or so. The bus voltage should come up to something just over 14 volts. If so, then the problem to be isolated lies with regulator, OV protection or associated wiring. If the alternator does not come alive, then it's time to get out the wrenches. Well speak to more details on regulators and OV protection in later chapters.

GOT A VACUUM PUMP PAD OPEN?

There's one more wound-field alternator of noteworthy capability because it is designed to install on the AND20000 style spline drive common to vacuum pump pads. For builders considering an all electric airplane, it would be a shame not to exploit the opportunity for driving two alternators from the same engine.

There are a handful of contemporary automotive alternators designs adapted to run on the vacuum pump pad. Most noteworthy is the B&C Specialties SD-20 illustrated in Figure 3-9.

Your's truly designed the first regulators for this product including a special version that permitted a 14 volt product to function in both 14 and 28 volt systems without having to rewind the field coil. This alternator starts out life as an Nipon-Denso 40A machine that receives a new front end-bell and shaft modifications to accept the spline drive.

This product has proven a stellar replacement for the stand-by generators common to Bonanzas and C-210s since about 1980. I did the regulator design for those generators and I was exceedingly pleased to be a player in replacing those products with the next generation of technology.

Figure Z-12 in the appendix illustrates the most practical utilization of this product . . . although a number of builders have crafted a Figure Z-14 architecture using the SD-20 paired with a larger main alternator.

This particular product represents the Cadillac of spline driven alternators small enough to fit into the space behind an engine formerly occupied by a vacuum pump. A really cool aspect of this product's design is the fact that it's

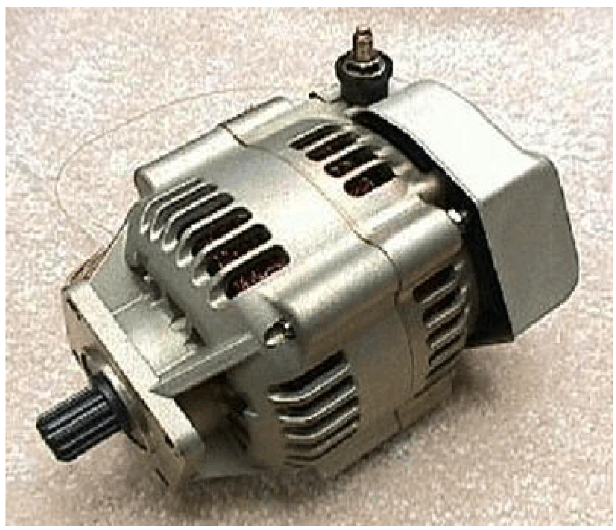
Figure 3-9. Exemplar Pad-Driven, Wound-Field Alternator (B&C SD-20)

derated in output power due to the low speed of a vacuum pump pad. This design features bearings rated for the side loads and operating speeds of belt drive. In this application, those loads, speeds and subsequent electrical loading is much less than original design goals. This product should demonstrate exemplary service life,

PERMANENT MAGNET ALTERNATORS

There is another form of low power alternator very suited to both primary power and stand-by service on OBAM aircraft. These parts have decades old ancestry in motorcycles and small garden tractors. Larger versions are found on Rotax

Figure 3-10. Spline Driven PM Alternator (B&C SD-8)

and Jabiru engines. This alternator is the ultimate in simplicity. Figure 3-11 speaks to the major components of a PM alternator. A stationary winding is surrounded by a cup shaped assembly fitted with magnets bonded to the inside surface. The stator winding has several 'poles' on it but there is generally only one strand of wire wound in opposite direction of successive poles. This configuration results in single phase AC power being produced by the magnets as they are rotated.

The practical power output limit for this configuration currently stands at about 250 watts max. There are some larger, 3-phase versions in the 400 watt class providing electrical power for larger garden tractors. To date, the smaller single-phase machines have seen the greatest application in OBAM aircraft.

This system is useful in aerobatic or VFR-Day only airplanes with limited avionics. Typical outputs are in the range of 8 to 20 amps at 14-volts for single-phase products and perhaps as much as 35 amps for 3-phase devices. Since the field of this of alternator is fixed, the output voltage is proportional to engine speed. A distinct advantage of this design is that there are no slip rings. Power is taken from a stationary winding and rectified in a combination rectifier/regulator assembly. There are no high wear parts in a PM alternator. No brushes and very lightly loaded bearings. This class of alternator promises a very attractive service life.

The regulators used with these alternators are special devices that have very little in common with regulators needed for the wound field machines we've already talked about. Unlike regulators for wound-field alternators, the PM alternator's output must be rectified from AC to DC power simultaneously with controlling it to offset variation in engine speeds and electrical system loads.

The spline driven SD-8 and it's belt driven cousins put electrical systems onto many Variez and Longez aircraft about 30 years ago. Even today, the SD-8 is this writer's first choice for implementation of the "all electric airplane on a budget" depicted in Figure Z-13/8 in the back of this book.

Figure 3-12 illustrates an aircraft adaptation of a belt driven PM alternator commonly offered on small tractors. Belt drive offers an opportunity to spin the alternator faster thus producing more output power from the same size machine.

PM ALTERNATOR FAULT ISOLATION

First, because the PM alternator is so simple, the probability

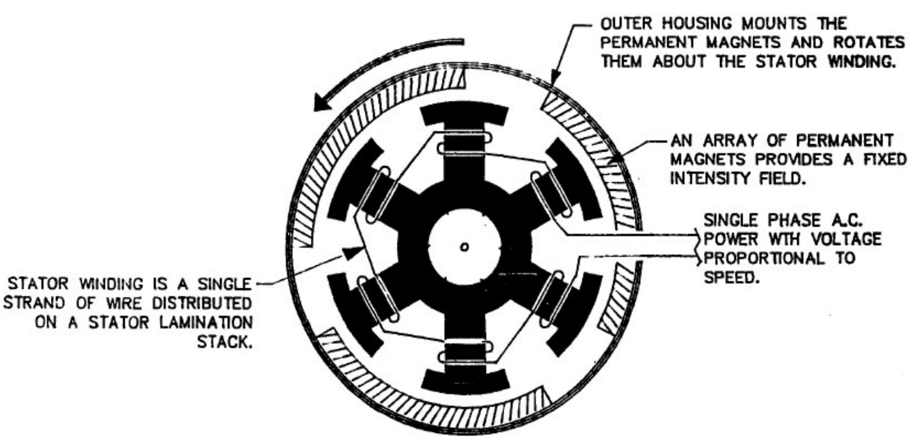

Figure 3-11. Major Components of the PM Alternator

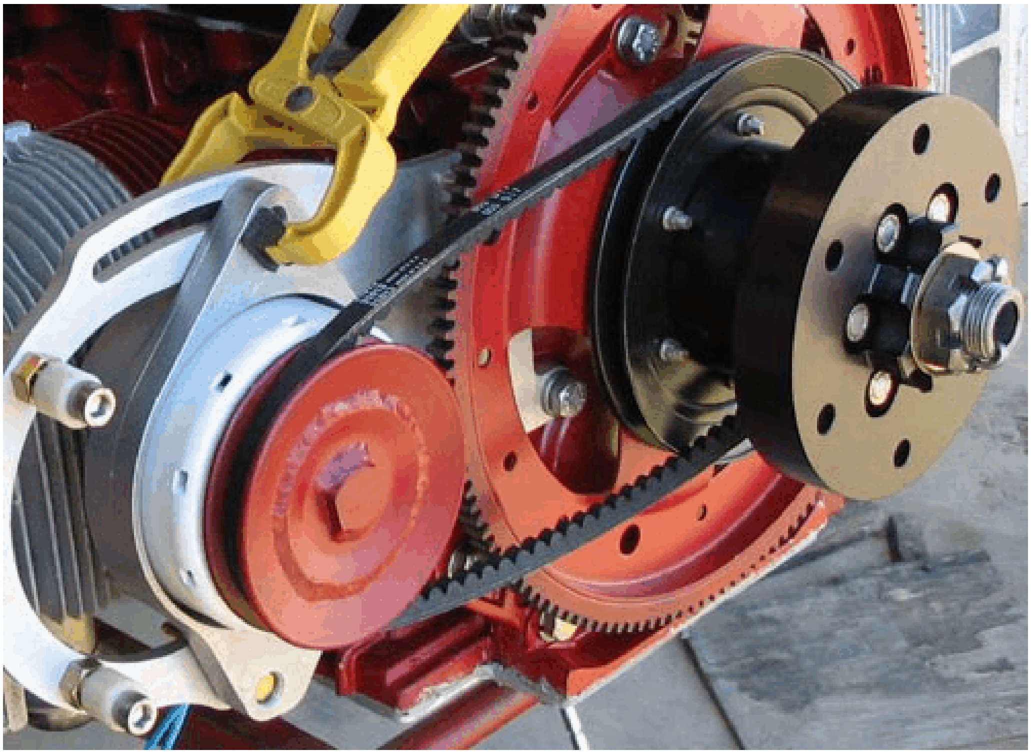

Figure 3-12. Belt Driven Adaptation of PM Alternator to Aircraft.

of failure in the alternator itself is very low. For virtually any PM powered electrical symptom, look at the wiring first, followed by the rectifier/regulator. The alternator's output voltage may be monitored for test and diagnosis with a voltmeter but remember, it is an AC voltage. In flight, the voltage from these machines may be as high as 30 volts.
We'll speak to the internal workings and unique functionality rectifier/regulators for PM alternators in the next chapter.

GENERATORS

Generators are still flying today on classic TC airplanes, on OBAM aircraft that use an engine taken from an older airplane, and several popular military trainers. If your electrical system power needs are modest and you make flights of reasonable duration so that the battery gets completely recharged in flight, there is no pressing need to replace a generator with an alternator. But they do tend to be much more troublesome than alternators.

Compare the construction of the alternator in Figure 3-2 to that of the generator in Figure 3-14. Here we find that the field assembly is the stationary part and the armature carries the power producing conductors. The current that flows in the power producing conductors of both the alternator and the generator is an alternating current. The commutator on the generator's armature provides a sort of mechanical rectifier by tapping only the conductor that is moving through the strongest portion of the magnetic field. It also provides a means for taking power from a moving assembly. The brushes of the generator have to carry the total output current of the generator as opposed to the brushes in the alternator, which carry only a few amps of field excitation current.

The electro-mechanical switching regulator common to generator installations will be discussed in detail in the next chapter where you will see extra 'relays' used to limit output current and prevent reverse current flow in the de-energized or non-rotating machine.

Figure 3-13 Belt Driven Generator.

Unlike alternators with self-limiting magnetics and built in rectifiers, the generator is not self limiting in its ability to produce output current nor will it automatically isolated itself from the battery if the engine stops or belt breaks.

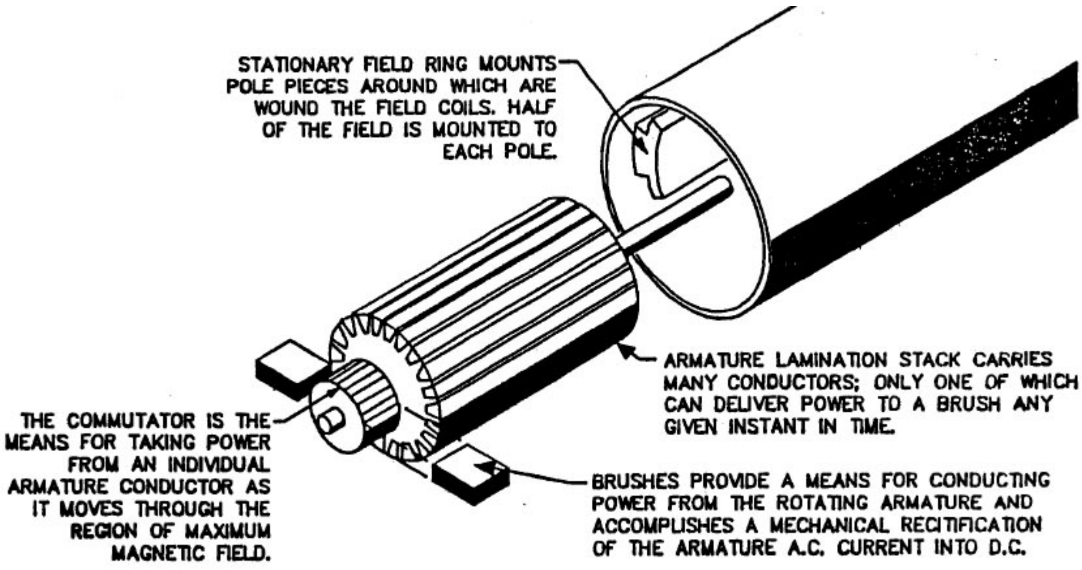

Figure 3-14. Major Components of a Generator.

Further, if the current limiter were inoperative or bypassed, a 20-amp generator would willingly deliver 35 amps . . . for awhile. Commutators and brushes would overheat as would the armature wires. It would be a race and perhaps a photo finish to see which one caved in first.

When the engine is turning too slow for the generator to produce a voltage greater than battery terminal voltage (remember, it takes 14-volts to charge a 12-volt battery) the generator must be disconnected from the system to prevent the flow of power back into the generator. For this task the generator's regulator assembly features "reverse current cutout" relay.

GENERATOR FAULT ISOLATION

If the generator output is zero, either the regulator, generator or wiring could be at fault. Use a voltmeter to see that there is voltage at the "B" terminal of the regulator with the battery switch on and the engine not running; check the wiring to the bus bar and the generator breaker if this voltage is missing.

Remove the cover from the voltage regulator and loosen the generator's belt tension. Manually close the reverse current cutout relay on the regulator. If the generator is mostly okay, it should spin up like a motor when you cause battery current to flow back into the generator. Gear driven generators will have to be dismounted for this test. If the generator will motor, it is most likely okay and you can try replacing the regulator.

Unlike alternators, generators are not are directly excited from the bus through their regulators. They depend upon residual field flux to "wake up" after the engine starts. If the airplane has been stored for a long period of time (or you're installing a new part), the generator may have lost its residual field flux and be unable to bootstrap itself on line. This condition is corrected by 'flashing' the generator's field. The act of doing the "motor test" applies full battery voltage to the generator's field windings. The residual magnetism left in the generator that successfully passed a motoring test may now come back alive as a generator after you replace the belt. In stubborn cases, flashing can be facilitated by having the engine running at 2000 RPM or so when you close the reverse current cutout contacts.

Generator brush wear is also a common cause for failure. A tear-down inspection will reveal this problem. You can prolong the life of the commutator by many hours if you do a tear-down inspection of the generator at every annual and replace the brushes ***before they fail***. In the act of failing much arcing and heat is produced, which is physically detrimental to the commutator. When replacing failed brushes or, if worn brushes are being replaced and there is a groove worn into the commutator's brush track, the commutator should be turned on an armature lathe with a diamond cutter. Commutator segments should then be undercut. Do not use sandpaper to clean up a dirty or corroded commutator. The sand will put microscopic grooves that are non parallel to commutator motion and accelerate brush wear. Use an abrasive rubber such as a typewriter eraser to remove heavy corrosion. A freshly turned commutator is the familiar bright copper color but brush track will soon turn a golden brown color when the generator is placed in service. This is the healthy glow of a happy commutator; don't polish it off.

Consider replacing bearings before they fail too. Take the old bearings to a bearing house and they will help you identify them and make suitable replacements at a fraction of the cost of bearings through aircraft parts distribution. Generator bearings will be sealed and pre-lubricated. If you're offered a choice of lubrication, go for high temperature.

A voltage set point or stability anomaly is the fault of the regulator. If the generator has burned armature windings or commutator, be sure to check the operation of the regulator after the generator is repaired or replaced. In fact, I think I'd always replace a regulator after a catastrophic failure of the generator. The failure of the current limit or reverse current relay could have been the original failure that resulted in a secondary failure of the generator. The undiagnosed bad regulator will just as happily wipe out your new generator too!

If you have no other options, generators can continue to provide useful service in the operation of your airplane but they are expensive to maintain, demand more preventative care and are generally limited in their ability to power more electro-whizzies in your airplane. If you have an opportunity to convert to an alternator of any genre', you're money and $time$ ahead for making the conversion. It's very difficult to find individuals with the tools and skills to do a good job on a generator rebuild. Suppliers of regulators is dwindling too.

LOOKING BACK IN TIME

It's interesting to compare the engine driven power generation technology available to us today with the products and markets first opened by the likes of Edison, Tesla, Westinghouse and Kettering. If you could go back in time and show them products we've been discussing on these pages, they would no doubt be amazed at the size, efficiency, and capabilities of these automotive DC power workhorses.

But the science, the simple ideas behind the operation of all these devices would be readily apparent and immediately understood. While modern materials and processes continually improve on our ability to meet evolving design goals, the science has and will continue to be as constant and relevant today as it was over 100 years ago.

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