Dynamotor Design

Nine Factors Involved in Dynamotor Design: Wattage Output and Input, Ripple Requirements, Continuous or Intermittent Duty, Ambient Temperature Conditions, Regulation, Weight and Size, Starting Characteristics, Service Conditions, and Vibration Requirements.

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A DYNAMOTOR, which is a combination motor and generator wound on a single iron stack, differs from a motor generator because it has only the common iron system, while a motor generator has separate iron circuits. Because of the common use of the iron by both the input and output, the action of a dynamotor is different from that of a motor generator. The output voltage, which cannot be regulated by changing the field excitation, could be expressed as follows:

$$E_{output} = \left[E_{in} - I_{n} R_{in} \frac{T_{out}}{T_{in}} \right] - I_{out} R_{out}$$

That is: The output voltage is equal to the input voltage minus the voltage drop in the input circuit (which is the voltage directly applied at the input commutator), times the turns ratio of output to input, minus the voltage drop in the output circuit. If the previous formula were analyzed, it would be noted that neither the speed or field excitation or flux appear in it. This is perfectly true, and it is one of the major features in the use of a dynamotor. When the input voltage varies, as it will on a battery or generator circuit, the output voltage changes by the same percentage. Inasmuch as the turns ratio is fixed once a unit is wound, there is no way of changing this ratio for purposes of controlling the output voltage.

Wattage output will be the governing factor in deciding the size of a unit. To maintain a normal temperature rise, the unit must be of sufficient size to dissipate the heat generated from the loss wattage of the unit. For instance, a 20-watt output dynamotor with 50% efficiency would have to dissipate approximately 20 watts of heat, while a 200-watt unit with 60% efficiency would have to dissipate approximately 130 watts of heat. (For a general illustration, it is assumed that all the losses are converted to heat.) The heat dissipation is handled in two ways. The first is to have a totally enclosed unit and to depend on the transfer of heat from the external surfaces. This unit will be the larger of the two classes. In the second method an integral fan is attached to the unit to draw air through it and thus cool it more effectively. By using a fan, the rating of a unit can be raised approximately two and a half times over the totally enclosed rating.

The heat losses may not be the limiting factor for a given wattage output. As wattage is made up of both voltage and current, an excessively high voltage with a small current may require a larger unit for the same wattage output, because the high voltage in the armature will require more room for extra insulation, and also creepage paths must be longer for external circuits. These extra precautions increase the size of a unit.

Input voltage also affects the size of a unit. For the same wattage output a 6-volt input unit will be larger than a 26-volt input unit. This is due to the fact that the current for the 6-volt unit is considerably higher than that for the 26-volt input. That means larger wire, bigger commutators and brushes.

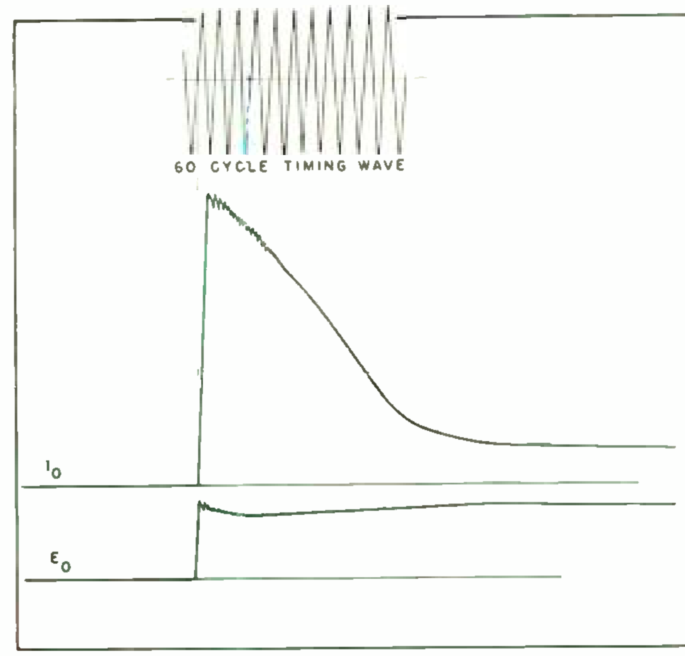
The size of dynamotor brushes is very important. The temperature of the commutator depends largely on the current density in the brushes. If the current density in the brushes is high, bad commutation will result, which will cause short life of both brushes and commutators. The grade of the brush must also be proper for the value of input voltage. When the unit runs, a film builds up on the commutators. This film varies for different grades of brushes, and each grade produces a film of different resistance. From this it will be seen that the grade of brush on the *A* side plays an important part in determining the voltage of the *B* side. If the input voltage is low, the brush must have low specific resistance and have a film of low resistance, or the voltage drop through the brushes and film would be too high a percentage of the input voltage.

One of the more elusive factors to be considered in designing a dynamotor is that of ripple. In producing d-c by means of a dynamotor, what one gets is not strictly d-c, but rectified a-c. In the rectifying, the resultant voltages vary by as much as 1 per cent from the actual direct current value. In other words 99% would be d-c and 1% would be variable d-c. This is variable d-c, because the amplitude changes, but the polarity does not. The normal way to measure the variable d-c voltage is to place a 2-mfd capacitor in series with a rectifier voltmeter and place these directly across the output. The capacitor blocks out the d-c voltage, but passes the variable component, which is read on the voltmeter. Brushes for a specific unit are chosen or discarded on their ability to commutate with a minimum of ripple. Anything that will affect the steady output of d-c will affect the ripple value.

It is well known that silicon iron has a different permeability in the direction of the grain than it has at right angles to it. If the laminations in the armature were stacked so that the grain was all in the same direction, the permeability of the complete armature would change as it revolved through 360°. This would cause the flux that flows through the armature to fluctuate and increase the variable part of the d-c output, which is known as ripple. In the early stages of development, it was thought necessary to rotate each lamination from the next one by one tooth, so that a uniform flux path would occur. Later investigation proved this unnecessary if the punch-

View of a dynamotor with a 5.6 v d-c input and 420 v d-c output.

Right: Observed running data on a dynamotor with a starting amp of 108 and starting time of .232 second. In this plot $E_A = 24.2$; $I_A = 15.5$; $E_B = 536$; $I_B = .450$.



ings are scrambled and random stacked.

In the normal motor or generator, the armature slots usually run straight and parallel with the shaft. In the dynamotor, to smooth out the abrupt change from minimum to maximum flux, the slots are skewed in a spiral so that the change is more uniform and gradual.

Along the same line, to further smooth out the changes in flux, it was also found very desirable to flare the tips of the pole shoe. The major part of the pole face is on the circumference of a circle with the center at the center of the armature shaft. The pole tips, from about one-quarter of the way in from the end must flare on a line tangent to the pole face circle at the one-quarter mark.

In the windings, it is very necessary that all coils have exactly the same number of turns. Most output coils are wound separately in forms and then inserted in the armature. In winding these coils, it is possible to vary by one or two turns, unless great care is observed or an automatic winding machine used. The variations of turns from coil to coil increases the ripple.

After the windings are in the slots, the coils must be connected to the proper bars, so that when the brushes pick up the voltage the coil sides will be in a neutral zone. If the lineup is not held very closely, the ripple will be high.

The surface of the commutator has an important function in keeping the ripple down. It should be free from burrs, scratches, and anything that might cause a brush to chatter. Some claim that the surface should be smooth as a mirror, and others that a very fine microscopic thread should be turned on the surface. Both methods have their good and bad points. Needless to say, the brushes must ride smoothly and steady to provide arcless commutation and produce good ripple characteristics.

The ripple must, of course, be filtered out for quiet operation of equipment used with the dynamotor.

In electronic apparatus, background hash is hard to overcome. Some of this hash is generated in the dynamotor and is picked up by the electronic system both as conducted and radiated noise. During investigations to attempt to reduce this value, it was discovered that the physical position of the input and output windings in the armature had an important bearing on the amount of hash generated. Originally the high voltage winding was wound in the armature first and then the motor winding was wound on top. With this method, it is possible to machine wind the motor winding and thus reduce the cost of the unit. However, the noise is considerably reduced by putting the motor winding on the bottom and the output winding on top. This is a more expensive way of winding an armature, but the better performance justifies the added cost. An additional method for reducing the hash is the addition of small bypass capacitors across the commutators and brushes.

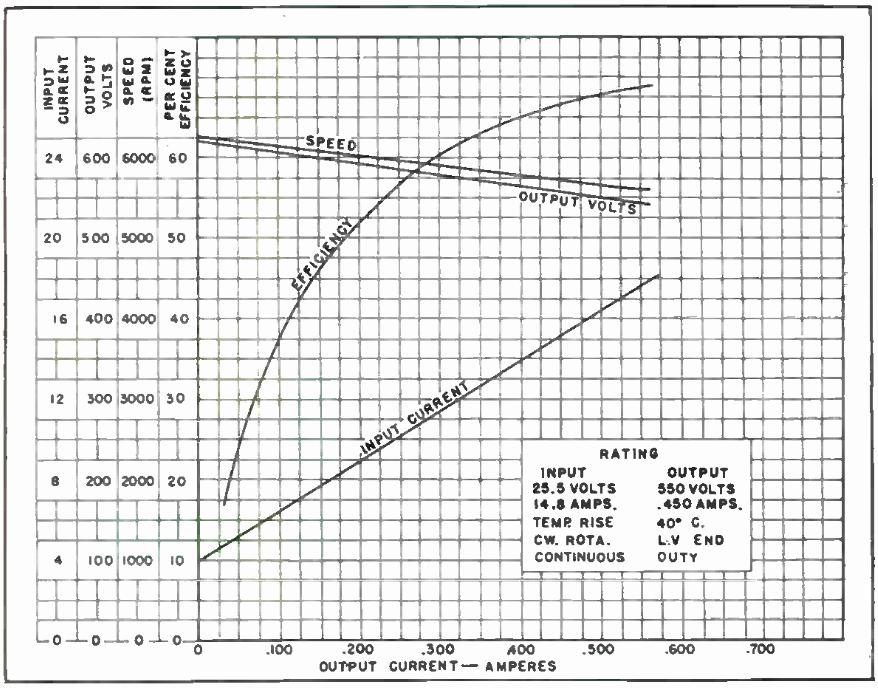
The next consideration is duty. Units are classed as intermittent or continuous. Continuous duty machines are always larger than intermittent duty ones for the same output watts. Temperature rise is the factor that governs the size of the dynamotor.

There are innumerable cycles for intermittent duty units. For instance, one cycle could be one minute on and three minutes off. That is a 25% duty cycle. Classing a duty cycle in per cent could be very misleading. A cycle of fifteen minutes on and forty-five minutes off is still a 25% cycle. However, a unit that could stand one minute on might not be able to stand fifteen minutes continuously.

There is another factor in the duty line to be considered, and that is the type of operation, or how often a unit is started and stopped. In some applications, a unit is started and runs for a long period of time before it is shut down. Another may start and stop very frequently. Special care must be exercised on units that start and stop many times.

Dynamotors are required to operate under many different circumstances from the poles to the tropics, from below sea level to fifty thousand feet of altitude, and from dry operation to that of operating immersed. The ambient temperature requirements influence the design of a unit in that the higher the ambient the larger the unit for a given output. The insulation must be capable of withstanding the higher temperatures without failing. This means thicker and heavier insulating materials. In turn, it makes the slots bigger to accommodate the thicker material. In the higher ambients, the heat transfer is less, so the losses must be kept down. This calls for heavier wire, which again makes the unit bigger and heavier.

Bearings and bearing lubrication are a problem, particularly if there is a hot and cold test to be met. And yet there is no successful high *and* low temperature grease. A single grease may be good for either high or low



Performance characteristics of a dynamotor with the input voltage maintained constant at 25.5 volts.

temperature, but not for both. For high ambient use, the bearings must be capable of being relubricated at short intervals. The most common type of bearing for dynamotors is the ball bearing. Plain or sleeve bearings have been used from time to time, but leave much to be desired from their performance.

Dynamotors are sometimes required to operate in explosive atmospheres. If this is so, special construction must be used. The explosion proof unit must be capable of having an explosive mixture set off inside the unit and not ignite an explosive mixture surrounding the unit. This means two things. The shell and end covers must be strong enough to withstand the force of the explosion and also have the type of joints that will not allow the flame inside to reach outside and ignite the surrounding mixture. This type of unit is the biggest and heaviest for any given rating because of its construction and the fact that it cannot be fan-cooled.

One of the main operating characteristics is that of regulation. This is expressed in percentage and is found by subtracting the full-load voltage from the no-load voltage and dividing by the full-load voltage with the answer multiplied by one hundred:

$$\text{Reg} = \left[\frac{E_{\text{no load}} - E_{\text{full load}}}{E_{\text{full load}}}\right] \times 100$$

When these measurements are made, the same input voltage must be maintained. The normal regulation for a dynamotor is in the neighborhood of 17%. To get good regulation, it is necessary to use large enough wire in the armature so that the *IR* drop for both the *A* and *B* winding is low. If this drop is low, then the difference between the no-load voltage and the full-load voltage would also be low, and good regulation would automatically follow. If a unit requires some special output value such as a high voltage, a small wire size must be used. The regulation would then be high. These factors are all interrelated and must all be considered when deciding on the proper unit for any particular application.

Dynamotors vary in efficiency from 45% to 69%, depending on which end of the rating a frame has to work. The more watts taken from a certain frame size unit, the higher the efficiency will be. This is due to the fact that a good percentage of the loss is more or less fixed for a given frame size. A dynamotor to produce 15 watts continuously on a 28- or 14-volt system would be 2¾" in diameter, 4½" long, and weigh 3½ pounds. A dynamotor to produce 60 watts continuously on a 28- or 14-volt system would be 4" in diameter, 7 3/16" long, and weigh 9 pounds, 11 ounces.

In the aircraft applications, weight and size are very important considerations. Space is not abundant in an airplane, and the more weight the plane has to carry as equipment, the less it can carry either as bomb load or pay load. In the commercial airlines, one extra pound has been estimated to cost as much as $1,200 a year. With this in mind, the engineer must use extreme ingenuity and be constantly on the lookout for new ways and means to decrease the weight and size and yet not sacrifice performance or service life.

The motor side of a dynamotor with low wattage output is normally a shunt motor. When the wattage increases, it is necessary to do something to keep the starting current from becoming abnormally high. For if this happens, injury may occur to some parts of the circuit, but the main difficulty is in the fusing of the units. When the starting current is too high, it takes such a large capacity fuse to handle it that there is no protection for the dynamotor even under 300% overload. The starting current is reduced by adding series turns to the field coil, thus compounding the motor end. It is possible in this manner to bring the starting current within allowable limits, but in doing so some regulation must be sacrificed. This is due to the added *IR* drop in the input circuit, which changes between no load and full load conditions.

Dynamotors are required to start fast and, in many cases, very often. They often must operate at −55° C after soaking at this temperature for a long period of time. These starting characteristics are obtained by the same series field that is used to reduce the starting current. This gives the necessary torque for quick starts and fast acceleration even at the very low temperatures.

All dynamotors are required to operate in a smooth and non-vibrating manner. This is accomplished by dynamically balancing the armatures. To dynamically balance an armature, it is set up on spring supported bearings ance, so that by reading the point to the bearings, and the amount of unbalance is read on a meter while at the same time a stroboscope lamp is synchronized with the point of unbalance, so that by reading the point shown while the armature is rotated, the operator knows where to add balancing solder to overcome the unbalancing couple.

Vibration may also be caused by rough bearings or by bearings that have been exposed to dirt and have picked up some dirt in the grease. The normal allowable maximum amplitude of vibration on the heads of a dynamotor is in the neighborhood of

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.0007" as measured on a vibrometer. The vibrometer is an instrument that multiplies small vibrations by means of a mirror and light beam, so that when the period of vibration is fast enough, the amount of movement shows up as a solid band of light on a calibrated glass scale.

Dynamotors often must operate at high altitude. The altitude problem in a dynamotor consist of brush and commutator wear, which also causes ripple and a large amount of hash or background noise. Dynamotors will normally operate up to about 20,000 feet before the effect of the lower density air is felt. At higher altitudes, the brush life becomes much shorter. An attempt has been made to overcome this fault by using altitude treated brushes. These brushes will do the job in some instances, but the brush life is still very much less than that at sea level. The only sure way to test altitude requirements is to flight test the equipment. The results obtained in altitude chambers still do not completely duplicate the results obtained by actual flight tests.

Multiple Input/Output Designs

All of the preceding discussion has been concerned with single input, single output units. Dynamotors have been built with as many as five individual windings. These windings have been divided into units with single input and four outputs or with double inputs and triple outputs. Any variation is possible, because any winding may be used either as an input or output by using the proper turns and wire size and making the correct connections.

A very desirable quality in a dynamotor would be to have a constant output voltage regardless of changing input voltage or load. A satisfactory way of doing this without the use of external regulators has not been devised, but engineers are working on this problem, and some preliminary patents have been filed. Units are being built, that have regulated outputs, by using a carbon pile regulator and they have proven very satisfactory.

A great deal of engineering effort is being applied toward the goal of smaller units and higher outputs along with the research toward regulating inherently. It should not be too far in the future before major developments are available to dynamotor users.