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PENALTIES IN PERFORMANCE OF THREE-PHASE, FOUR-WIRE, 400-CYCLE MOTORS CAUSED BY THE OPENING OF ONE PHASE

INTRODUCTION

The aircraft motor manufacturers have expressed a need for a common understanding with users as to what performance can be expected when 400-cycle motors, not designed with this function in mind, are operated with one line open circuited on a three-phase, four-wire system. Consequently, a subcommittee, A-2M, Motors, operating under SAE Committee A-2, has reviewed the requirements and characteristics of 400-cycle aircraft type motors when operating under these conditions.

The power system and motor design parameters of 400-cycle motors are interrelated to such an extent that absolute recommendations as to load, speed, torque, and the effect on a particular system when operating with one phase open, could lead to serious difficulty if not thoroughly studied and applied.

Therefore, the A-2M Subcommittee, based on the enclosed informational data, advises that specification of "emergency two-phase operation" of a normal three-phase motor be rarely used. However, in those cases in which this type of operation is mandatory, the operational parameters should be clearly specified to permit proper design and engineering. Permissible reduction of performance should be included in these specifications in order to best adapt the motor to the application with the minimum size and weight penalty.

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1. SCOPE:

The scope of this SAE Aerospace Information Report (AIR) is to present a guide for the determination of probable power output and the effect on the aircraft system that will be experienced when operating three-phase motors with one phase open. Unfortunately, the above subject cannot be resolved by specific rules. Modern aircraft or missile electrical systems are composed of a wide variety of electrical and electronic components. These components react differently under identical impetus due to the latitude of their design. This latitude of design must be allowed wherever possible to the accessory designer due to the various specification requirements.

Therefore, it cannot be over-emphasized that the effect on the airplane or missile system, as well as motor operation, of three-phase motors on two-phase power must be thoroughly investigated.

2. REFERENCES:

There are no referenced publications specified herein.

3. DESIGN AND RATING:

The design and rating are important considerations in the successful operation of three-phase motors on two-phase. Two-phase operation as discussed herein is defined as a motor operating from a nominal three-phase, four-wire system with one supply line open. Table 1 is a comparison of three-phase and two-phase motor operation at constant torque. Table 2 is a comparison of motor performance holding rated current. It can be shown from the limited number of motors presented here, and the wide diversity in the characteristics, that a broad latitude exists on the relative three-phase and two-phase performance that can be expected from aircraft motors. The motors presented are typical and were tested with a power supply many times larger than the rating of the motor, thereby minimizing the effect of unbalanced voltages on the generator characteristic.

3.1 From a consideration of the performance characteristics at rated voltage and frequency the following general conclusions can be made for two-phase operation:

a. Stall torque: 1/3 normal

b. Maximum torque: 1/2 normal

c. Speed: Slightly less

d. Efficiency: Reduced approximately 10%

e. Amperage: Increased approximately 50%

f. At rated current the available torque for two-phase operation varies from zero to approximately 40% of rated, depending on the motor design.

3.2 It has been pointed out that the maximum torque and starting torque are reduced due to two-phase operation. The inrush is usually somewhat greater than normal also, which has the effect of reducing the starting torque further due to the incremental reduction in applied voltage at the motor terminals. However, the important consideration with two-phase starting is that the accelerating torque characteristic may not be the same as when operating three-phase, due to such design criteria as winding pitch, harmonics present, and other parameters. In fact, some motors have a negative torque cusp in their speed-torque, two-phase characteristic which does not exist under three-phase operation. Therefore, it is apparent that a close examination of the generators, electrical system, voltage and frequency limits as well as the motor and motor load are necessary to be certain of always starting a load under two-phase conditions.

3.3 If rated current per phase is taken as the criteria for motor operation, it has been shown that the motor may develop from 40% to zero torque, depending on the particular design and rating. However, the heating effect on some motors may be greater than operation under normal three-phase conditions, again depending on design. Voltage unbalance of less than 10% does not appreciably affect the torque capabilities of a motor. However, unbalanced voltages do increase the watts loss in a motor, therefore the relative size of a motor and the supporting generating system and characteristic are important considerations. It should also be kept in mind that multiple aircraft generating systems are sometimes run as a split bus system, even though equipped to parallel. Auxiliary power plant operation may have to be considered with additional problems of voltage and frequency not usually encountered.

3.4 Since there seems to be a growing demand in the use of thermal protectors, it is well to look at the affect of two-phase operation on some of these devices. The thermal protector installation to be successful, must be matched with the electrical and thermal inputs to the motor. If the current signal to the protector is in error, and the heat distribution in the motor changes, it is difficult to see how the thermal protector can do its job over the complete temperature, load, three-phase, and two-phase operational range without nuisance trips or motor overheat.

4.5 Other auxiliary devices sometimes integral with motors are brakes and clutches, and unless a brake is specifically designed to operate under two-phase conditions, it is highly improbable that the device will operate without drag with the accompanying heat in the brake parts. Increased and rapid wear and additional motor load may also result, or the brake may not release at all.

4. EFFECTS ON GENERATOR SYSTEM:

Again, the effect of relative rating of motor and generator is significant. The type of voltage regulator and regulator system is important and two-phase operation could produce serious overvoltage on a single phase of the three-phase system. Low voltage on a single phase could also be produced, again depending on conditions and the system. Continuous operation under adverse system conditions could overheat a generator in a multiple generating system. Line-to-neutral overvoltage sensing devices may trip before circuit breakers or fuses and outages of an alternator may be caused when least desired. The effect of harmonics on alternator operation introduced by two-phase motor operation must also be considered.

5. POWER FEEDER SIZE AND PROTECTION:

The routing of wire in an aircraft or missile, while not a romantic subject, must be considered as a very important part of this topic. From generation to utilization, the engineer must plan routing of wires and control circuits with their protective devices and switches. The wires may run in bundles, open wires, or a combination of both, and through different ambient temperatures. The gage of wire is usually determined by either voltage regulation or current carrying capacity, as determined by the load - in this case a motor. If the wire size were determined by current carrying ability, the increased current due to two-phase operation may seriously reduce the life of the wire, or permanent damage may result. If voltage regulation were the criteria for wire size selection, the increased voltage drop due to increased currents would further adversely affect the motor. In addition to the above, another consideration to be made is the wide band of tripping characteristics between fuses, limiters, sensing units and circuit breakers of the same current rating. Coordination of these elements with two-phase motor operation over the usual ambient conditions encountered may be difficult.

6. FREQUENCY AND VOLTAGE EFFECTS:

The previous discussion has been based on constant voltage and frequency. Table 3 is a tabulation of the effect of varying frequency at constant voltage on the characteristics of a 3-1/2 horsepower motor. The combined effect of voltage and frequency can be proportioned from the data presented herein. It is well to point out that the frequency characteristic was obtained from an infinite source bus. The effect of two-phase operation on the motor characteristic that was mentioned previously under constant voltage and frequency certainly would produce even greater deviations when voltage and frequency variations are taken into account.

7. REMARKS:

The data tabulated in Table 1 through Table 3 was obtained from some 400 cycle aircraft motors which were intended for aircraft applications. Since operation of these motors with one line open was not an original design consideration, it was decided to test these motors under this condition to determine what the effect would be. The results are tabulated to demonstrate the wide range of performance that was experienced on this group of machines which were not designed for two-phase operation from a three-phase four-wire, aircraft power system.

TABLE 1 - Comparison of Three-Phase and Two-Phase Performance at Rated Torque of Some 400-Cycle Aircraft Motors

Rating	Quantity	Three-Phase Operation (%)	Two-Phase Operation (%)
1/8 horsepower	Average Current	100	134
	Power factor	36	45
200/3/400	Efficiency	63	54
	Speed (% of syn.)	92.5	88.8
Continuous duty	Torque	100	100
	Maximum torque	425	225
Weight 2.12 pounds	Stall torque	390	150
	Stall current	225	268
1/30 horsepower	Average current*	100	145
	Power factor	41	30
200/3/400	Efficiency	63.5	56.5
	Speed (% of Syn.)	92.5	88.5
	Torque	100	100
	Maximum Torque	435	200
	Stall torque	435	160
	Stall current	294	310
1/2 horsepower	Average current*	110	185
	Power factor	85	55
200/3/400	Efficiency	83	75
	Speed (% of syn.)	93	92
	Torque	100	100
	Maximum torque	172	116
	Stall torque	90	40
	Stall current	383	452
3-1/2 horsepower	Average current	100	145
	Power factor	63	70
208/3/400	Efficiency	76	69.1
	Speed (% of syn.)	94.6	91.9
Gearhead motor	Torque	100	103.5
	Maximum torque	383	190
	Stall torque	328	111
	Stall current	440	448

* Currents for this rating were expressed as % Rated Line Current vs % Rated Torque