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ROTATING ELECTRICAL MACHINERY
on
RAILWAY LOCOMOTIVES AND RAIL CARS
and
TROLLEY, GASOLINE-ELECTRIC AND OIL-ELECTRIC COACHES

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RAILWAY MOTORS AND OTHER ROTATING ELECTRICAL MACHINERY

on

RAIL CARS AND LOCOMOTIVES

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PREFACE

General

In undertaking the preparation of rules for standards for rotating electrical equipment for railway cars and locomotives under the Rules of Procedure of the American Standards Association, it has been necessary to cover a much wider field than was included in the AIEE Standards for Railway Motors which were published in 1925, approved as American Standards in 1928 and form the basis of this standard. In the first place, the scope of the rules has been changed to include all rotating electrical machinery forming a part of the power equipment of electrically-propelled railway cars and locomotives (including trolley, gasoline-electric and oil-electric coaches). In the second place, it has been found desirable to add new rules covering principally, rating, commutation, and overspeed tests. In the third place, the old rules must be brought up-to-date as modern methods of ventilating electrical machinery have changed the situation in many respects. It is therefore felt necessary that some explanatory notes should be added to the rules in order to give the users of the rules a clearer understanding of the reasons for them.

Ratings and Application of Direct-Current Railway Motors

Thirty years ago separately-ventilated railway motors were practically non-existent. The earliest street car motors were of the open type like ordinary industrial motors, but were soon followed by fully-enclosed motors which were the rule for about fifteen years. Then the motors with separate ventilation were introduced on heavy locomotives and were followed by the development of self-ventilated motors for street cars. Now the non-ventilated motors are practically obsolete. This has made a great difference in the size and weight of the motors.

Whereas the continuous rating current was 40 percent of the one-hour rating for enclosed non-ventilated motors, the continuous rating of the self-ventilated motor is about 60 to 80 percent and for separately-ventilated motors 80 to 100 percent of the one-hour rating.

The current densities in the windings of the non-ventilated motors at the continuous ratings are so low that the windings have relatively large thermal capacity and can carry very heavy overloads based on the continuous current rating. The self-ventilated motor, however, usually has a much higher proportional current density at its continuous rating and correspondingly less thermal capacity and less overload capacity. The separately-ventilated motor has still less relative thermal and overload capacity. The thermal capacity is usually the determining factor for the overloads the motor can carry.

The necessity for some measure of the thermal capacity of the motor has led to the retention of the one-hour rating for railway motors through a period when a greater and greater reliance has been placed on the continuous rating. There is no question as to the necessity for a good measure for the continuous capacity of a motor in terms of current at different voltages, which corresponds closely to the rms current in service in the case of most d-c motors, but the thermal capacity is also of great importance. For this reason the one-hour rating of railway motors has been continued in these rules as a connecting link between the old and new type motors and an additional rating has been added in an appendix which it is believed will afford a much better measure of the thermal capacity of ventilated machines than can be given in any other simple way and may eventually supersede the one-hour rating. This is called the *thermal capacity rating*.

The thermal capacity of a railway motor or a generator on an oil or gasoline-electric or a motor-generator type equipment is a measure of its overload capacity so far as the temperature of the windings is concerned. It is arbitrarily expressed in terms of the average number of seconds per degree required for the temperature of the machine to rise from an average running temperature to the maximum permissible temperature when operated at a definite overload, preferably high enough to limit the duration of the test to not more than 10 minutes.

The test given in the appendix is offered in the hope that it may prove to be a good measure of thermal capacity and will provide a test that is inexpensive to make which will assist in the comparison of generators of different origins. If it does this it will be quite useful. Cooling curves are also recommended both with and without ventilation on separately-ventilated machines.

Application

In applying ventilated motors the thermal capacity as well as the heating and cooling curves should be carefully considered. Any motor which has a small thermal capacity will in almost all cases require a larger margin in any given service than a motor with the same continuous rating but a larger thermal capacity.

Alternating-Current Motors

The foregoing applies almost as well to single-phase commutator type motors as to the direct-current motors except that the application of separate ventilation of a-c motors is practically universal, the rms current does not give as complete a measure of the I^2R loss in the conductors as in the d-c motors, and the armature speed and therefore core loss are more important. However, the thermal capacity rating can be applied.

Voltage Ratings

Standard d-c railway motors running on power from trolley or third rail in America are usually rated at 600, 750, 1200 and 1500 volts, which correspond to the full-load substation voltages, or half of these voltages where motors are connected permanently two in series. Where line voltages of 2400 or 3000 are used, motors have always been connected with two or more in series.

Traction motors receiving current from generators carried on the same vehicle may cover a wider range of voltage than motors fed from trolley since the power plant goes with the motors, the voltage is not subject to the surges of a trolley system, and the power back of the motors is much less.

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Substation Voltage

The voltage at the substation for direct-current railway networks should be such that the voltage applied to a motor will not exceed the rated motor voltage by more than 10 percent as a normal value.

Single-Phase A-C Commutator Type Motors

Since a-c motors are invariably fed at a low voltage from transformers carried on the car or locomotive, the voltage on the motors can be varied at will between extreme limits; and the same motor can, of course, be used with any line voltage where the transformer is designed to take care of this. Since the continuous-current capacity falls off as the voltage rises from some intermediate voltage, on account of increased core losses and eddy losses in conductors, it is considered desirable and the best practice to rate the motors not at the maximum voltage at which they can operate, but at a lower voltage which will convey a better general idea of the tractive effort and service capacity of the motor. Hence, the rule included which rates the motor at the voltage and current which will develop its continuous horsepower rating at not exceeding 70 percent of its maximum guaranteed service speed. (70 percent has been substituted for 60 percent which was previously proposed to meet the wishes of the European committees.) Voltage taps above that will be known as overvoltage taps.

Commutation

The AIEE Rules for railway motors did not offer any rules in regard to commutation. It is recognized that there are no definite criteria for gauging commutation which could be used as a basis for acceptance or rejection of a motor on a stand test. However, since commutation tests are included in the new IEC Rules, some rules are included herein similar to the IEC Rules and modeled to a considerable extent on the rule in the proposed ASA Standards for Rotating Electrical Machinery.

It is obvious that every motor operated from a railway network carrying intermittent loads will be subjected to voltage fluctuations, the value of which will be dependent on the resistance and reactance of the line, the currents carried, and the variations in voltage at the substation. The voltage fluctuations at the substations may be due either to poor regulation of the generators in the substations where generators are used, or to fluctuations in transmission line where rotary converters or rectifiers are used, or where alternating current is fed directly into the railway network from transmission lines through lowering transformers. It is reasonable, therefore, that all motors receiving current from trolley or other contact conductor should be able to commutate momentarily voltages 25 percent in excess of their rating.

Where direct-current motors are operated permanently two in series without mechanical connection or other slip preventive, they should be able with full field connections, to stand 1.5 times their rated voltage with six-tenths of the continuous rated current without injury either from commutation or overspeed.

When motors are operated permanently with three or more in series without mechanical connection, automatic means may be required to limit the voltage and speed of any motor to a safe value.

When motors are to be used in regenerative braking they should be tested as generators, covering the extremes of current and voltage. It is well known that motors will commutate more safely when operating as generators than when motoring.

In general, it may be stated that railway motors should be constructed with good running balance and have commutators well seasoned before being put in service. This is especially important with modern high-speed motors. It is practically impossible for any motor to commutate satisfactorily with the armature running out of balance or with a rough commutator.

Brushes should run without chattering, which destroys the contact on the commutator and may spot it, besides increasing friction so much as to affect the efficiency and cause excessive heat on the commutator. Chattering may be the product of unduly hard brushes, high commutator bars, improper fit in holders, or some other obscure cause. It should not be permitted, especially during efficiency or loss tests.

Heating and Temperature Limits

Table I in the Rules gives maximum observable temperatures in service recommended for motors with Classes A and B insulation. The life of Class A insulation is affected directly by the temperature, and it is recommended that motors with Class A insulation in no case be operated at higher temperatures.

Class B insulation will stand higher temperatures than given in Table I without direct injury from temperature and some motors are operated regularly at higher temperatures. The chief objection to such operation is that, when broadly applied, difficulties will sometimes arise due to alternate expansion and contraction of conductors which may in time wear through the insulation. This is particularly true on armature windings which are subject to great stresses from centrifugal forces, and also gear vibrations.

It is suggested that series field coils with Class B insulation may be operated safely at higher temperatures because of their construction and lack of centrifugal forces and vibration to which armatures are subject.

Temperature Rise on Test

Table II gives the permissible temperature rises of rotating electrical machines on which the various ratings are based, assuming "normal values" of temperatures as given in Table I with air temperatures of 25C. It will be noted that the same rises are specified for both one hour and continuous ratings for Class B insulation. This leaves the difference between "normal" and "peak" temperatures as a margin for higher ambient temperatures. These ratings will be applicable in the great majority of cases for machines in service, but it is advisable for allowance to be made for service with Class A insulated motors in localities where temperatures exceed 25C for a considerable part of the time.

Generators for Oil and Gasoline-Electric Equipments

The design of a generator of this class is quite different from an oil engine driven generator in a power station supplying power to a traction system. In the latter case, the generator would be designed for constant voltage and since the engine could never carry more than a definite maximum load, the required generator continuous capacity would be materially less than the engine rating, depending on the load factor.

On the other hand, it is universal practice to have variable-voltage generators for use on rail cars or locomotives, and since the engine power is limited they must

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be able to utilize the full output of the engine over the entire range of current and voltage, the one varying inversely as the other. It is customary to furnish generators having a continuous current rating corresponding to full engine output with much less than their maximum voltage so as to be able to operate continuously over a relatively wide range of current and voltage. The maximum continuous-current rating should be equal to the combined continuous motor currents of the traction motors when they are operated always in parallel,—but this may be reduced by 10 or 15 percent where series parallel control is used. This is usually the case.

The maximum *continuous* voltage is largely a function of field coil temperatures, whereas the maximum *operating* voltage is a function not only of temperature as determining the resistance, but of exciting voltage and generator saturation. The continuous rating is therefore defined in terms of kilowatts output available at the generator terminals over a stated range of current and voltage.

The range of current with corresponding inverse range of voltage at full generator speed imposes severe commutating conditions on the generator, but they are mitigated somewhat by series-parallel operation of the traction motors which reduces the maximum demand.

The thermal capacity rating similar to that described for motors is also recommended for generators. The one-hour rating can be omitted since there is no precedent for its use with generators, and therefore one of the main reasons for continuing it for railway motors is lacking.

Generators for Motor-Generator Locomotives

A generator driven by a synchronous motor on an a-c motor-generator type locomotive differs from the generator for the oil-electric locomotives in that it must be able to carry overloads, but the general rating will be satisfactory since the capacity of generator applied in any case will depend largely on the service to be performed as well as on the rating of the engine or motor that drives it. The synchronous motor would ordinarily be able to carry 25 to 50 percent above its rating for short periods and the generator must do equally well. The capacity of the generator must be suited to the capacity of the traction motors in any case. A variable-voltage generator rated at a low voltage increases the service capacity of the equipment very materially, especially where regenerative braking is required.

Driving Motor of the Motor-Generator Set

This is usually of the single-phase synchronous type. It should have capacity to meet the requirements of the service as determined by the capacity of generator to be driven by it.

Induction Motors and *Phase Converters* should be designed for the particular service they are to perform. They should conform to the same temperature limits and dielectric tests as other electrical machines.

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