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FLASHING OF DC MACHINES CAUSED BY SHORT CIRCUITS

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ABSTRACT

Experimental work on the flashover characteristics of a 300-kw Diesel-driven dc generator is described and the effects of certain parameters and a theoretical explanation are given. The observations reveal the effects of initial speed, load, and commutating ability on the susceptibility of a dc machine to flashing. Additional work is necessary, however, in order to correlate more fully the observations from high-speed motion pictures with the theoretical analysis and to develop means of reducing the tendency toward flashover.

PROBLEM STATUS

This is an interim report; work on the problem is continuing.

AUTHORIZATION

NRL Problem E01-05R
NS 676-003

FLASHING OF DC MACHINES CAUSED BY SHORT CIRCUITS

BACKGROUND

Flashing at the brushes of commutating machines has been a common difficulty for many years. Little progress has been made in overcoming this obstacle owing to the involved nature of the factors concerned and the difficulties in analyzing them. Despite the lack of rigid analysis of the conditions causing flashing a great many attempts have been made in the past to reduce flashing by artificial means. The use of barriers was partially successful in diverting the arc and thus reducing the damage to those parts most vulnerable to the arc. However, the application of this principle to shipboard machinery appears to be definitely limited by the lack of space.

The design of new propulsion systems for submarines is placing renewed emphasis on achieving a solution to the flashing problem. Machines having new voltage ranges, speeds, and ratings are being designed. The requirements for operation are approximating the conditions that will produce flashing in normal designs. In order to operate these systems successfully and to produce others in the future in which such operating conditions will exist, it is important that information concerning the flashing characteristics of dc machinery be known.

A survey of literature on flashing of dc machinery yields a few studies on the subject, but these deal either with artificial means of reducing flashing or else the theories proposed are misleading and contradictory. Therefore it becomes immediately apparent that if the Navy is to obtain the peak currents required from the dc machines on shipboard installations it is essential that the relationship of flashing and transient performance be investigated and correlated.

CAUSES OF FLASHOVER

Flashing of direct-current generators and motors can result from several factors. Some of the more generally accepted causes are: Jumping of the brushes as a result of vibration and high bars; surges of load, that is, sudden removal; and large overloads or short circuits. Some authorities claim that the sudden application of load (not of short-circuit magnitude) will also result in flashing. The presence of carbon or other conducting foreign matter on the commutator (partially shorting the segments) can increase the susceptibility of a machine to flashover due to any of the above causes or may in itself be the direct cause of the flashing.

This report is to be concerned with flashover resulting from overload. The presence of foreign material on the commutator will be considered as secondary, since it will only accentuate the effect of overload.

FLASHING DUE TO OVERCURRENT

In order to study the flashover characteristics of a direct-current dynamo and to determine the effect of certain factors, a 300-kw, 345-volt, 1200-rpm generator was selected. The schematic of electrical connections and instrumentation is shown in Figure 1[1]. The after-battery contactor of a Westinghouse control cubicle of the SS-228 class of vessel was employed to apply and interrupt the load current for the generator. Flashover was detected from oscillograms taken of the voltage and current of the armature. Examples of these oscillograms are shown in Figure 2. Flashing manifested itself by irregularities in the current and voltage traces (Figure 2A), whereas the absence of flashing produced a smooth curve (Figure 2B). The more severe cases of flashing that have been observed produced far greater variations in the output current, as can be seen in Figure 2C. The observed fluctuations in output current during flashover are to be expected since the arc shunts part of the current from the external circuit. A comparison of oscillograms with photographs of the commutator obtained with a high-speed motion-picture camera (3000 frames per second) substantiated the use of the oscillograph data as a measure of flashover. However, as will be pointed out later, these oscillographic records cannot necessarily be used as an accurate indication of the time for initial flashing currents.

A clearer understanding of the contribution and effects of the factors to be considered will result if the theoretical considerations of flashover phenomena are discussed at this point. The application of an overload to a dc generator results in a shift in the point of commutation from the brush axis to an axis α degrees away and in the direction of rotation. The magnitude of the shift is a function of machine design, speed, and overload. In instances where the overload is of short-circuit magnitude the point of commutation always appears to shift to a point beyond the brush edge, thus causing arcing. It is this arcing current which establishes the conditions for flashing, but which must be distinguished from flashing current. Arcing current is caused by imperfect commutation and is in the reverse direction to flashing current. This is illustrated in Figure 3. The currents resulting from brush arcing extend just a few segments at the most beyond the trailing edge of the brush and the arc will be extinguished when the voltage from brush to commutator is less than that required to sustain the arc. (There is also a position beyond this point at which this voltage will be zero.) Ionized gases, however, resulting from the brush arcing will be carried around the armature by the rotating film of air over the surface. Thus the arcing current does not carry around to cause flashover, but the ionized gases that exist may result in the production of flashover if sufficient voltage exists between brushes or brush to commutator to sustain an arc.

Measurements and calculations of brush-to-brush voltage at peak current for low-resistance short circuits have shown that it can be as much as 50% of the initial terminal voltage of the generator. Thus on 300-volt machines the brush-to-brush voltage can easily be as high as 150 volts. The data obtained by Hellmund[2] indicate

[1] *All figures appear at end of report.*

[2] *Hellmund, R. E., "Arc Characteristics Applying to Flashing on Commutators," AIEE Trans., 56:107-13, January 1937*

that this is sufficient to produce flashover when considered in conjunction with the ionized film of gas existing over the surface of the commutator.

On referring again to Figure 3, it can be observed that as the ionized gases are swept around the commutator they extend across a greater potential difference, that is, the potential difference between brush and commutator is increasing. When this potential difference is high enough the arc will strike, thus establishing the flashing current. As the commutator continues to rotate, the arc may be carried to the brush of opposite polarity. Thus complete flashover is established.

These considerations of flashover phenomena stress certain factors, namely:

(1) Arcing current is related to commutation and is the main producer of ions.

(2) Flashing current is in the opposite direction to arcing current.

(3) Flashing results from the ionized film of gas that envelops the commutator, and is initiated where the brush-to-commutator voltage is high enough to sustain an arc with the ionized condition of the gases present.

The exact time required to establish the necessary conditions for flashing and ultimately complete flashover is not clear at present. The theory above would indicate that considerable randomness in time would exist, but that the time would be a function of commutator emf, the quality of commutation during the first instance of short circuit and the speed of rotation. The speed of rotation enters because it determines the time required to spread the ionized gases over the commutator to the regions of higher potential difference. According to the idea proposed here, flashing on the leading edge of the brush is initiated only after the ionized gases have been carried from the previous brush by rotation of the commutator.

Results presented in Figures 4, 5, and 6 partially substantiate this concept of flashing time. It is to be noted that the observed times show considerable randomness and in general are higher near the region of no flashing. However, at the higher voltages, which represent more severe flashing conditions, the time of flashing is approaching values of approximately 0.008, 0.010, and 0.012 seconds for 1200, 1000, and 800 rpm respectively. This time is closely equal to the time required for a commutator segment to rotate between brushes of opposite polarity. Due to limitations in measuring time with a high degree of accuracy on the oscillographic records, these data cannot be used to draw definite conclusions. However, they do indicate a relationship to the several factors mentioned above. It can be stated as an approximation that the time for complete flashover may be as short as the time required for a segment on the commutator to rotate between brushes of opposite polarity. Flashing currents may occur in even shorter time intervals.

EFFECT OF INITIAL LOAD

The previous discussion and theory advanced on flashover indicate that the operating conditions of a dc machine prior to large overloads may affect its susceptibility to flashover. Figure 7 shows the effect of one variable, namely, initial load, on flashover. It will be noted that increasing the initial load increases the tendency for the generator to flash, or, in other words, requires a reduction in the terminal voltage over that at no load if flashing is to be prevented. There appear to be at least three factors that relate the flashing to initial load conditions. These are (1) response time of interpole flux, (2) peak value of short-circuit current, and (3) initial ionized gases resulting from commutation of steady-load current. The response of the interpole flux to transient loads is illustrated in Figures 8 and 9. This data was obtained on a 90-hp, 250-volt motor employed as a generator. It will be noted that not only does the interpole flux lag behind the change in current, I_a, which produces this flux, but due to the cross-magnetizing component of armature reaction the magnitude is greatly reduced. A slight advantage is to be had, however, by starting from initial full load over no load in that some interpole flux has already been established. Thus, commutation during short-circuit currents would be improved. This would lead one to believe that a generator shorted when carrying full load would be less susceptible to flashing over than one initially at no load.

Any improvement that may result from this initial interpole flux resulting from full load prior to short circuit is evidently more than offset by the last two factors. The peak current for full-load conditions is nearly 30 percent higher than that for no load. This may reduce the apparent gain in interpole flux noted in Figures 8 and 9, where a smaller percentage change in peak current is noted. The last factor, ionized gases resulting from commutation of load currents prior to short circuit, would also tend to increase the susceptibility of a machine to flashing when short-circuited while initially loaded over no load. Even though commutation may appear perfect at normal load, ionization of gases will always occur at the brush, which will in turn be spread over the commutator as a thin layer.

EFFECT OF SPEED

The speed of rotation has a pronounced effect on the susceptibility of a machine to flashing, as shown in Figure 10. It will be observed that with increasing speed the threshold value of terminal voltage for flashing decreases. Evidently this results largely from the increased reactance voltage that accompanies the increased speed. Other factors such as change in air-gap flux distribution, deionization time, effects of increased current with reduced speed, and time of response of interpole flux may also be of significance. Further study is required to evaluate these.

EFFECT OF BRUSH SHIFT

Experimental results obtained with brush shift are found to substantiate the theory that brush arcing plays an important part in flashing. These results are shown in Figure 11. Shifting the brushes against the direction of rotation increases brush arcing over that with the brushes on neutral, whereas a shift in the direction of rotation will reduce the brush arcing. The effect, as suggested by the theory, would be to increase the susceptibility of the machine to flashing in the former case and reduce it in the latter. This is found to be in agreement with the evidence of Figure 11.

It appears that the higher magnitude of peak armature current resulting from the brush shift must be considered in interpreting the results. An inspection of the curves of Figure 11 and a comparison with the data on Figure 7 which depicts the effect of load variation, might lead one to the conclusion that the susceptibility of the generator to flashing was due largely to the current rather than to the other factors that have been mentioned. This conclusion would be based on the observation that in the two examples, changing either variable (load or brush position) resulted in increasing the peak current for corresponding voltage and as a result the line representing the transition from no flashing to flashing had a negative slope. However, such a conclusion that relates flashing only to magnitude of armature current is not substantiated by the data of Figure 10, where it is seen that the line representing the boundary of the region of no flashing has a positive slope; that is, higher current is associated with higher armature voltage. This appears to offer conclusive proof that the concepts of the causes of flashing in the several cases cited must include other factors than just current alone. These factors, which have been previously mentioned, are air-gap flux distribution, response of interpole flux, deionization time and armature circuit inductance.

FUTURE WORK

Although the results to date of this investigation have answered some of the pertinent questions regarding flashing, further experimental results are required to correlate the relative magnitudes of effect of the various factors. In particular, knowledge is needed on the distribution of flux in the air gap during the transient resulting from short circuit; the time variation of this quantity is also of importance. Another factor worthy of consideration is the rate of change of interpole flux and its importance to the flashing phenomena.

Further knowledge of the effect of these factors on flashing may result in new techniques and methods of extending the speeds of dc machines; improving their short-time overload characteristics; and decreasing their susceptibility to flashing.

CONCLUSIONS

The results of this study are not complete at the present time; however, certain conclusions can be reached regarding flashing characteristics of dc machines as a result of large overloads or short circuits. These are as follows:

(1) Flashing currents result from the presence of ionized gases over the commutator surface, which are produced by brush arcing. An improvement in commutation or removal of these ionized gases will reduce the susceptibility of the d-c machine to flashing.

(2) The time elapsed after the application of transient overload before flashing exists is approximately equal to the time required for a commutator segment to rotate from a brush of one polarity to the next of opposite polarity.

(3) Flashing currents do not necessarily always connect adjacent brushes. They may span only part of this distance; that is, the arc may exist from the brush to the commutator on either side of the brush.

(4) Increasing the initial speed of rotation or initial load accentuates the susceptibility of a generator to flashing due to overload currents.

* * *

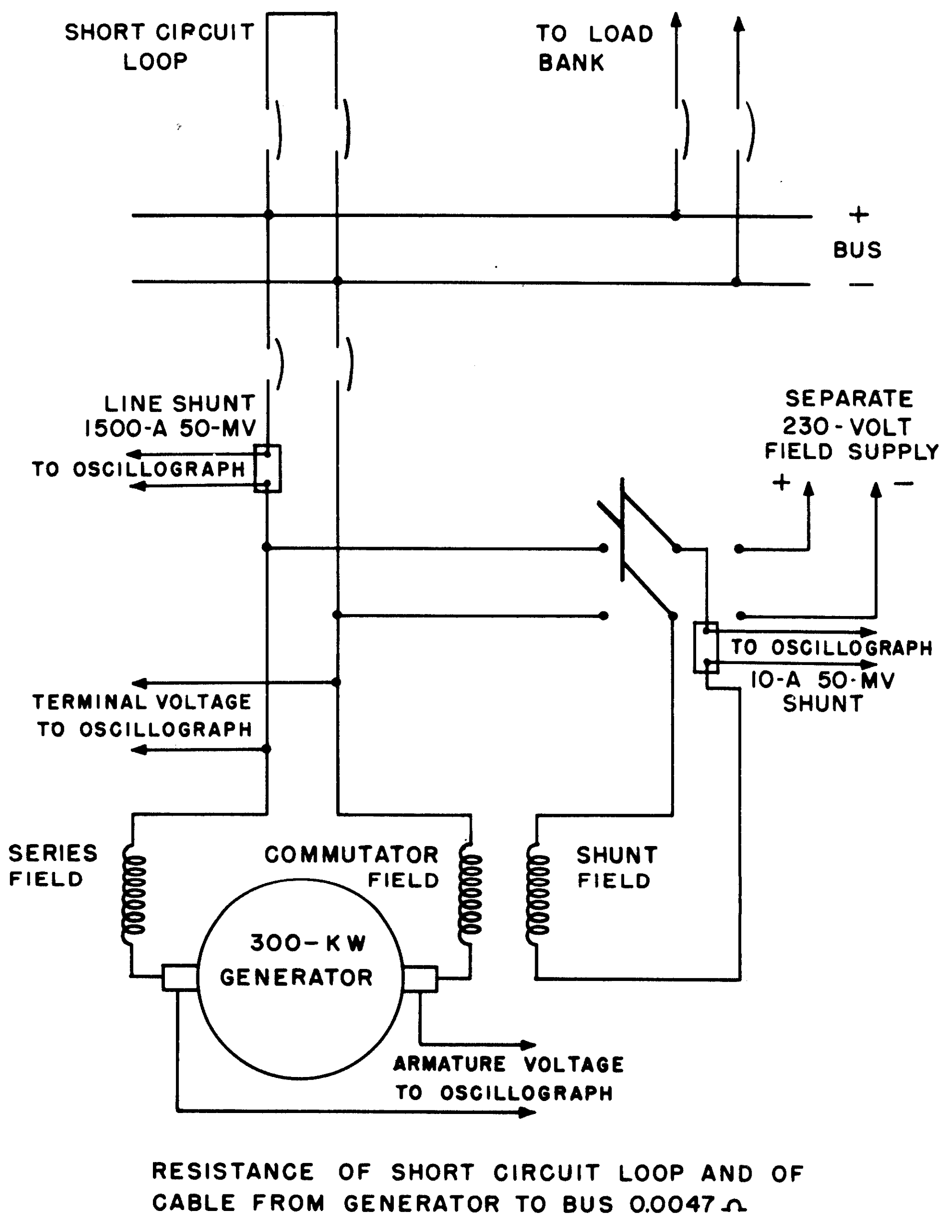

Figure 1 - Schematic diagram of power and metering circuit for 300-kw generator

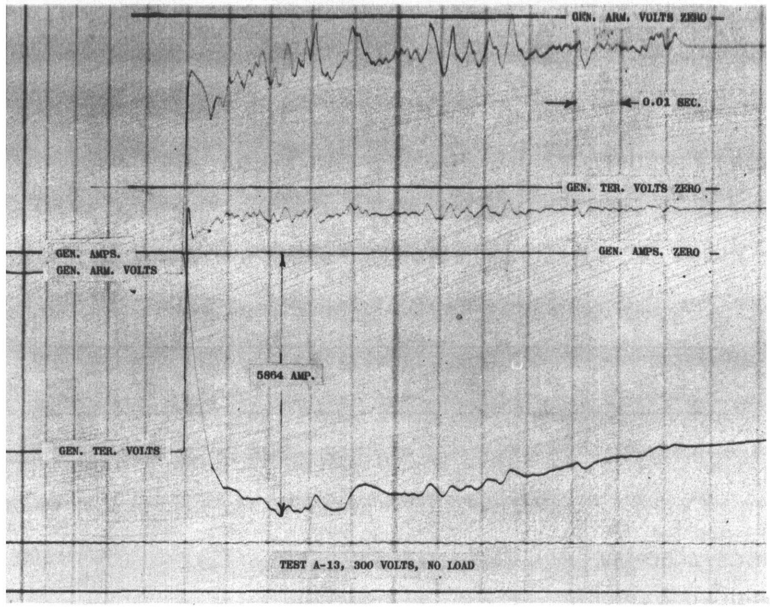

Figure 2a - Oscillograms of the transient armature current and voltage during short circuit. Initial conditions: 300 v, no load, 12 rpm

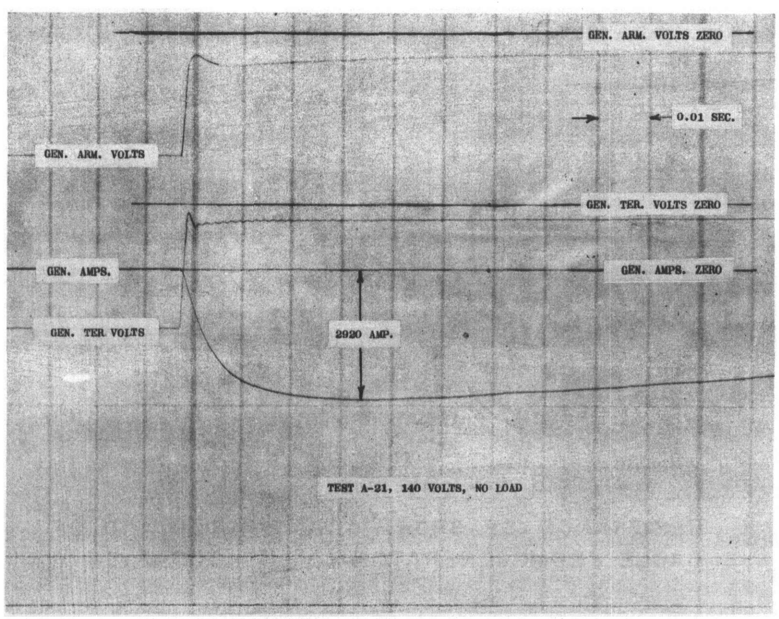

Figure 2b - Oscillograms of the transient armature current and voltage during short circuit. Initial conditions: 140 v, no load, 1200 rpm

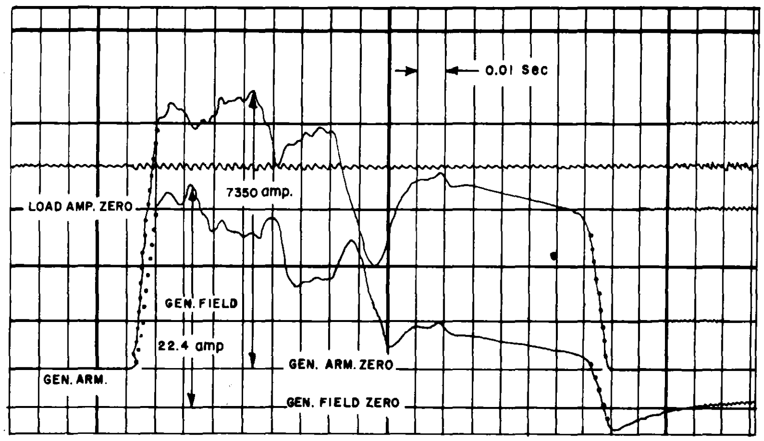

Figure 2c - Oscillograms of the transient armature current and voltage during short circuit. Initial conditions: 345 v, no load, 1200 rpm

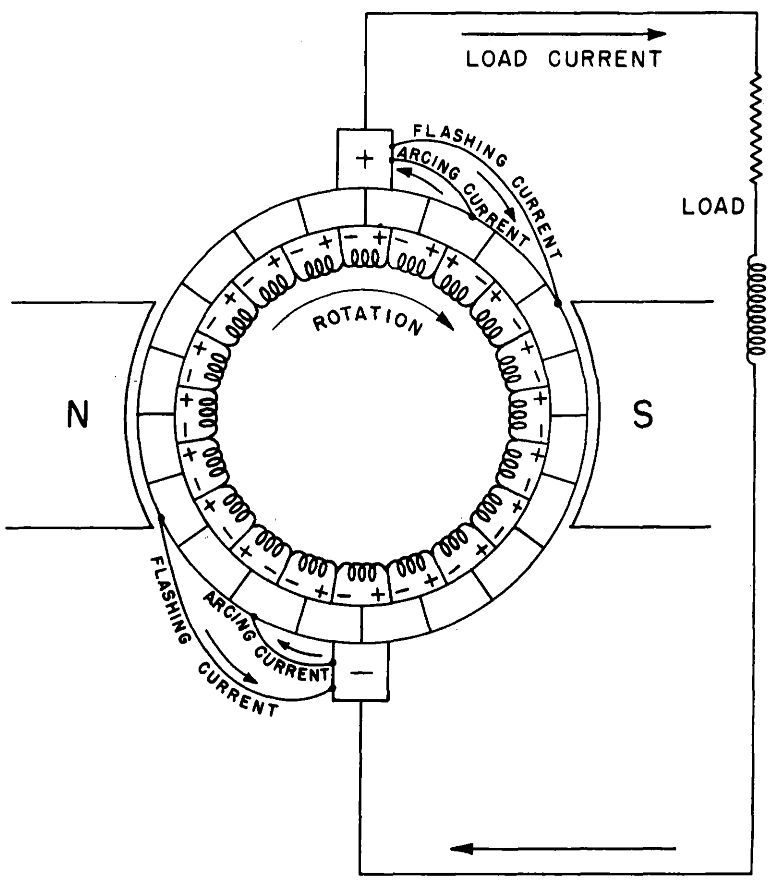

Figure 3 - Commutating characteristics during short circuit showing arcing and flashing currents

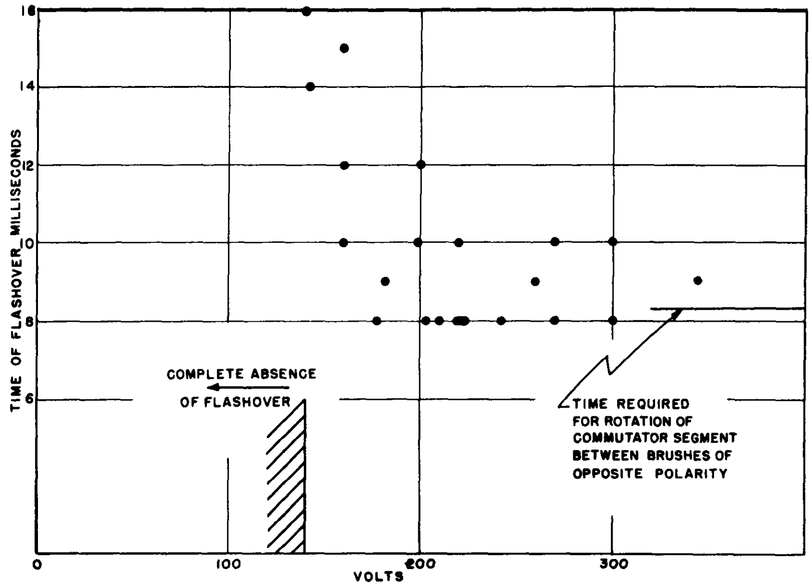

Figure 4 - Flashing time of a 300-kw generator at 1200 rpm

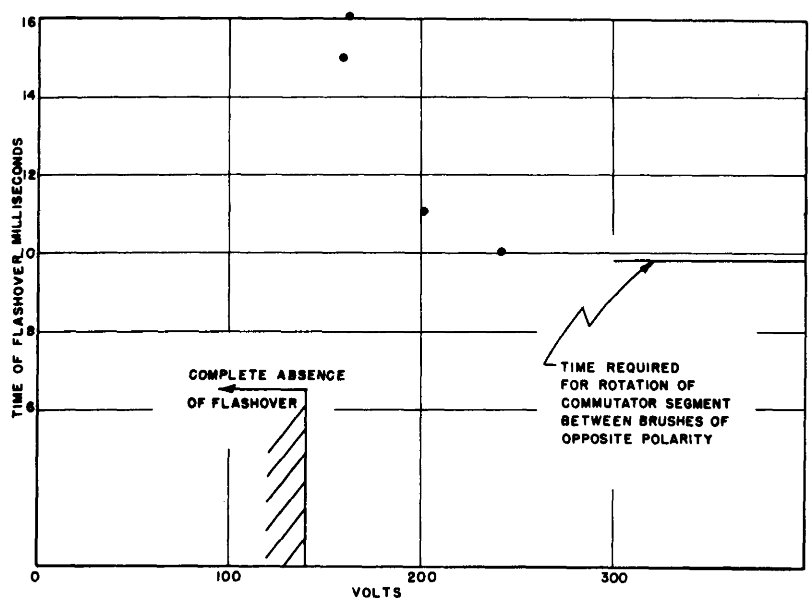

Figure 5 - Flashing time of a 300-kw generator at 1015 rpm

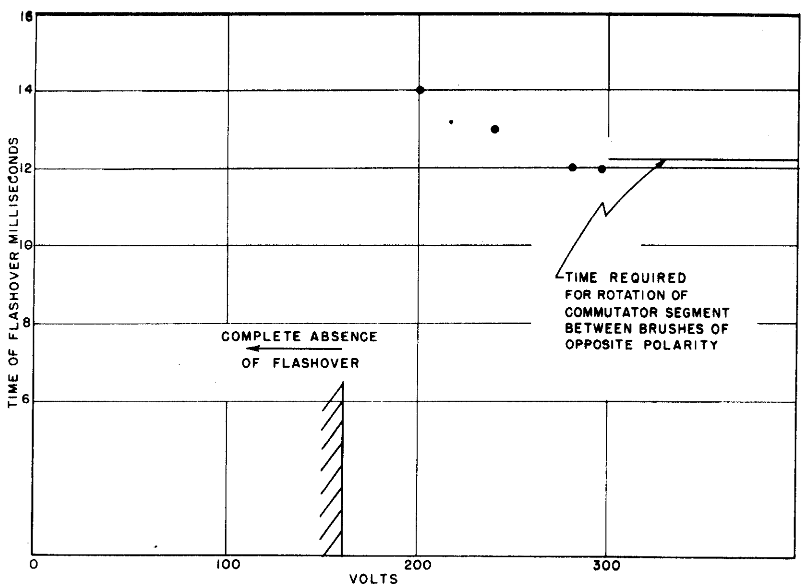

Figure 6 - Flashing time of a 300-kw generator at 800 rpm

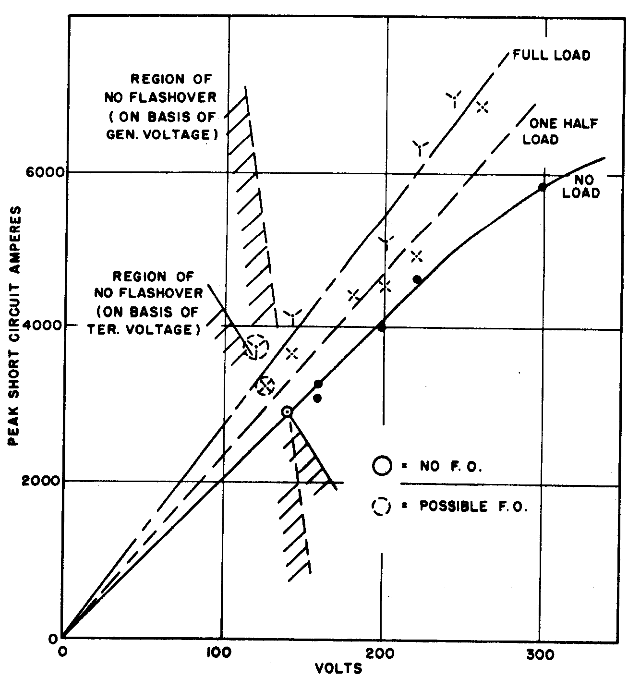

Figure 7 - Effect of initial load on generator flashing

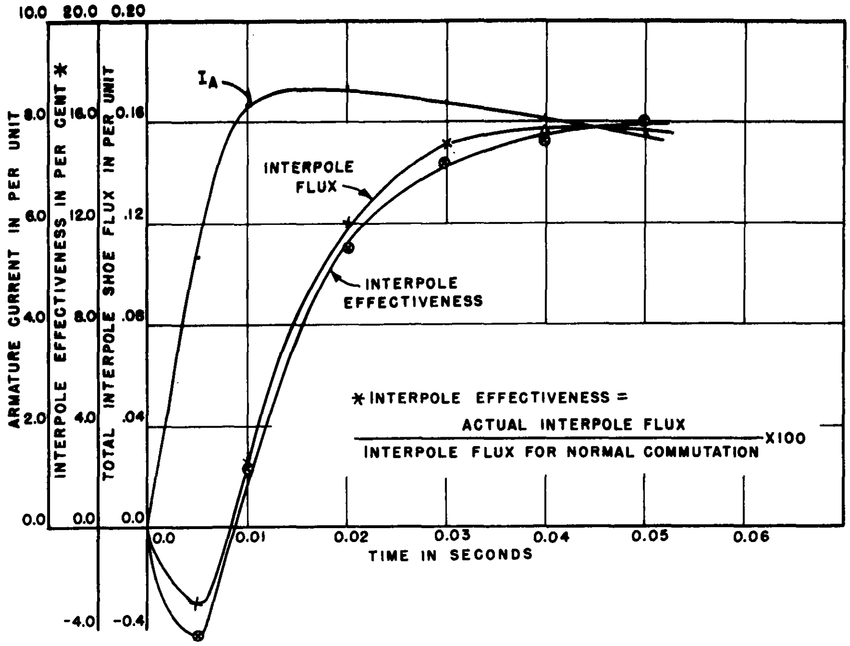

Figure 8 - Interpole effectiveness during transient rise in armature current, at no initial load. (Motor 90 hp, 250 v, 298 amp, 1750 rpm)

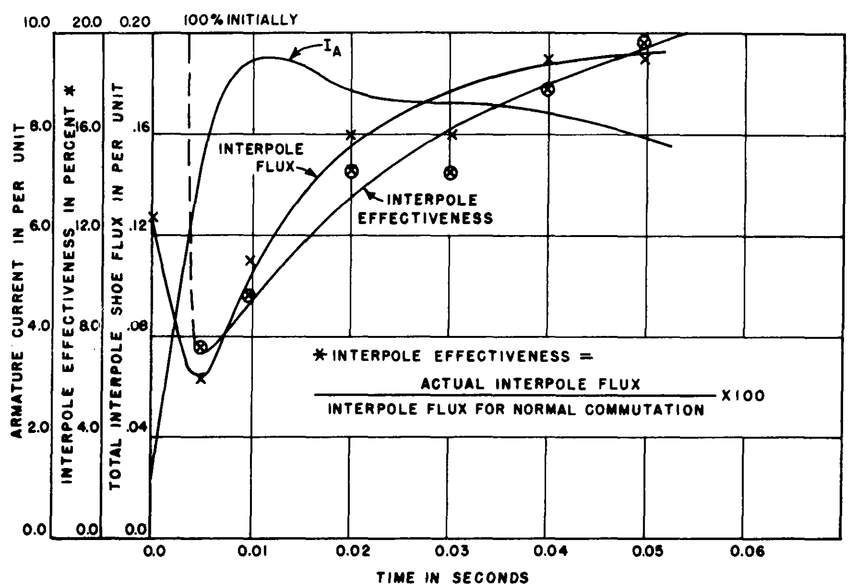

Figure 9 - Interpole effectiveness during transient rise in armature current, at initial rated load. (Motor 90 hp, 250 v, 298 amp, 1750 rpm)

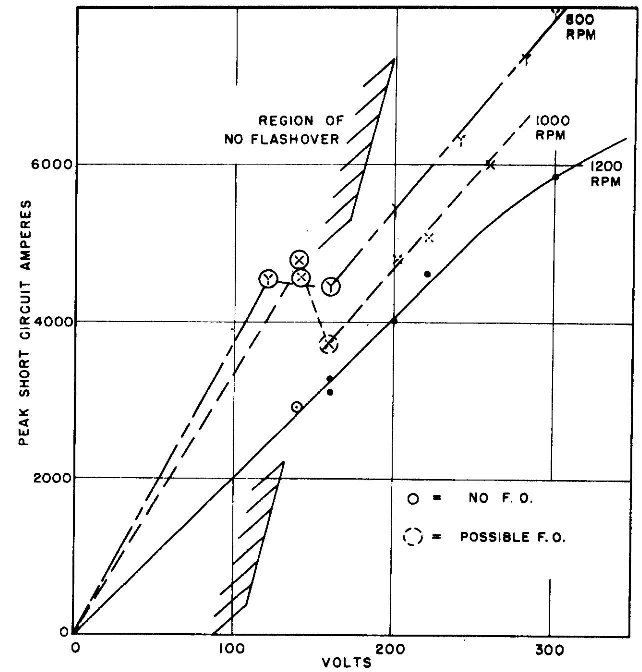

Figure 10 - Effect of speed on generator flashing

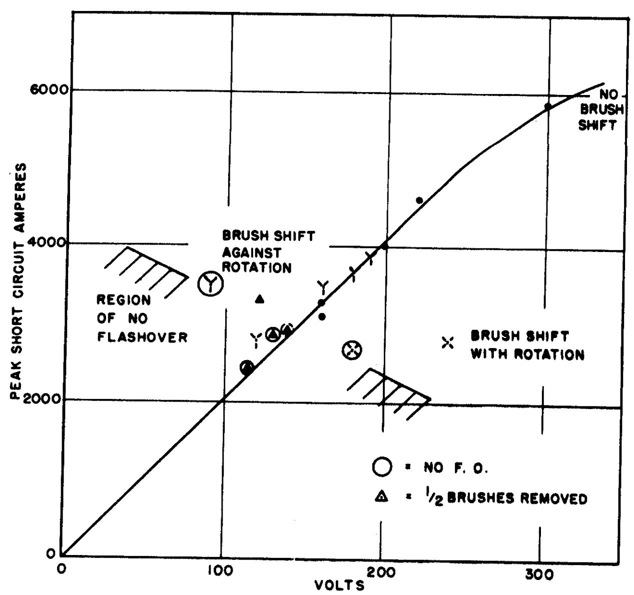

Figure 11 - Effect of brush shift on generator flashing

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