THE EFFECTS OF SUPPLY FREQUENCY ON THE PERFORMANCE OF A.C. FUSES

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SUMMARY:

Computer programs are used to predict the short circuit performance of a.c. fuses at various supply frequencies. Two ranges of low voltage fuses are examined in this way to compare their performance at 50 Hz and 60 Hz. The 400 Hz performance of L.V. fuses is also considered because they are occasionally used at this frequency. Finally, the performance of high voltage fuses, normally used at 60 Hz, is examined when they are installed in a 25 Hz system. Such practice sometimes occurs in North America.

1. INTRODUCTION

Most of the world's a.c. electricity is generated at 50 Hz or 60 Hz. There are some exceptions for which fuse manufacturers have to cater, e.g., 400 Hz in some low voltage applications and 25 Hz in some high voltage installations.

Fuses are therefore proved at either 50 Hz or 60 Hz, and the validity of the resulting test data is sometimes questioned when fuses proved at one frequency are proposed for use at the other. Thus the North American Standards [1,2] specify maximum values of I^2t and peak current for low voltage fuses related to 60 Hz, and European manufacturers offer fuses which have been proved at 50 Hz. The approvals authorities concerned accept 50 Hz test evidence, but occasionally question the validity of some of the recorded parameters in regard to their applicability to 60 Hz systems.

The suite of computer programs developed by Wilkins [3] is therefore used to examine the performance of fuses at both 50 Hz and 60 Hz, and the results are compared with actual 50 Hz test data to demonstrate the efficacy of the programs.

Since the programs have been shown to be reliable, they can be used with confidence to predict the performance of fuses under conditions at which it is not practicable to test, e.g., at 400 Hz and 25 Hz. This paper reports investigations into performance at both of these frequencies.

2. L.V. FUSE PERFORMANCE AT 50 HZ & 60 HZ

2.1 Verification of Programs' Efficacy

Data on two ranges of fuses commercially available in North America is used to verify the efficacy of the computer programs. The fuse types are HRC1-J and HRC11-C to reference [2]. Type HRC1-J fuses are also specified in reference [1], where they are identified as Class J. Both types were proved in the U.K. using 50 Hz sources. Whilst both ranges are rated at 600 V in North America, the HRC11-C range was actually tested at 660 V, + 10%.

Table 1 gives the major parameters recorded on approval tests, and shows how the computer predictions compare with those values. The table also gives the standards' limits for I^2t and peak current for the fuses concerned. Since work is proceeding to produce common North American fuse standards from the existing UL and CSA standards, these limits are referred to as "USC limits" in the table.

The predicted peak currents are generally slightly less than the recorded values on test, but there is good correlation between actual and predicted clearing I^2t values. There is also good correlation between other parameters not shown in the table (e.g., clearing time and arc voltage). In general, the fuses produce values of peak current which are substantially less than the specified maximum values with the exception of the 600 A rating in the HRC11-C range. The latter produced 90.9% of the maximum value when it was tested at 50 Hz, and it might therefore be argued that it would have exceeded the limit if it had been tested at a different arcing angle in a 60 Hz circuit. The North American standards specify that the arcing angle may be between 60° and 90° when fuses are subjected to tests at their interrupting rating (200 KA in the case of the subject fuse types). Therefore even at a given test plant setting, peak current can vary significantly over this admissible arcing angle range. The performance of the 600 A rating of the HRC11-C range is therefore examined in detail in Section 2.3 of this paper, to demonstrate that it would comply with the standard under the worst test conditions at 60 Hz.

The performances of the 30 A and 60 A ratings in the two subject ranges were also examined, and their let through values at 50 Hz were well within the 60 Hz limits. These results are omitted in the interest of brevity, it being reasonable to assume that conclusions reached about the performances of the larger current ratings are applicable to these smaller ones.

The clearing I^2t requirements for HRC1-J fuses are stringent, and so inevitably the actual test values approach the permitted limits, particularly as current rating increases. The predicted performance of this range therefore merits close examination.

TABLE 1 Let through values of fuses when tested at 200kA, compared with computer predictions for same fuses at same circuit parameters

		HRC1 - J fuses			HRC11 - C fuses		
Fuse Rating Amps	Data* Status	Arcing Angle Degrees	Peak Current Let through KA	Clearing I^2t A^2 sec x 10^3	Arcing Angle Degrees	Peak Current Let through kA	Clearing I^2t A^2 sec x 10^3
100	TD	75	12.8	38.1	62	21.1	189
	CP	75	12.3	40.7	62	17.7	180
	USCL		20	80		32	500
200	TD	77	24.7	245	64	32.2	705
	CP	76	23.6	250	65	31	766
	USCL		30	300		50	2000
400	TD	77	37.7	923	76	58.6	2855
	CP	77	36.9	933	75	54.7	3003
	USCL		45	1100		75	6000
600	TD	65	50.3	2280	69	90.9	11020
	CP	66	47.8	2200	69	87.5	12800
	USCL		70	2500		100	12000

* TD = Test Data CP = Computer Prediction USCL = USC Limit

2.2 The HRC1-J range at 50 Hz & 60 Hz

In Table 1, the arcing angles for the tests vary from 62^o to 77^o. The maximum values of clearing I^2t and peak current do not necessarily occur within such a range. Computer predictions have therefore been obtained over the complete range of 60^o to 90^o allowed by the standards. The results are shown in Figs. 1 to 4.

The values fluctuate over the arcing angle range, and the scales of the figures are chosen to exaggerate these fluctuations. Thus in Fig 4 the values of clearing I^2t for a 600 A fuse at 50 Hz change significantly at an arcing angle of about 77^0. Such fluctuations occur when a small change in closing angle produces a disproportionate effect on the rate of rise of fault current (see Fig 5).

Table 2 gives a statistical analysis of the clearing I^2t data shown in Figs. 1 to 4. The maximum and mean values at 50 Hz are slightly greater than those at 60 Hz, except that the maximum value of the 100 A fuse at 60 Hz is 1.1% greater than the 50 Hz value.

2.3 The HRC11-C range at 50 Hz & 60 Hz

Table 1 shows that HRC11-C fuses easily comply with the limits specified for I_p and I^2t. The tests were taken at 738 V, and only the 600 A fuse yielded values which approach the specified 600 V limits. Fig 6 gives the results of a number of predictions obtained for the 600 A fuse. Predictions for other current ratings in this range show similar trends to those on the HRC1-J range, and so they are not detailed in this paper.

2.4 Observations on the 50 Hz & 60 Hz data

2.4.1 Arc energy values at 50 Hz are invariably greater than those at 60 Hz. The fuses themselves are therefore stressed more when they are tested at the lower frequency.

2.4.2 At a given arcing angle, the 60 Hz clearing I^2t value can be greater than the 50 Hz value. However this difference does not exceed 5% (e.g., the HRC1-J 600 A fuse at arcing angles of 77^o to 83^o - Fig 4). An approvals engineer might therefore multiply a 50 Hz test value by 1.05 in order to compare it with the specification limit. If this criterion had been applied to the test values detailed in this paper, the fuses would still have complied with the standard.

2.4.3 The peak current (Ip) values at 60 Hz are invariably greater than those at 50 Hz, but the fuses generally have no difficulty in meeting the standard requirements in regard to this parameter. In the worst case, the 60 Hz value is about 11% greater than the 50 Hz one (i.e., the HRC1-J 100A fuse at an arcing angle of 74^o - Fig 1).

3. L.V. FUSE PERFORMANCE AT 400 HZ

Some electrical systems in aircraft are supplied from 400 Hz sources, and a few commercial/industrial installations also require a 400 Hz supply at 380/415 V. In the latter case, the kVA rating of the installed plant can be quite large (e.g., 225 kVA). It is therefore of interest to consider how l.v. industrial fuses are likely to perform in such an installation.

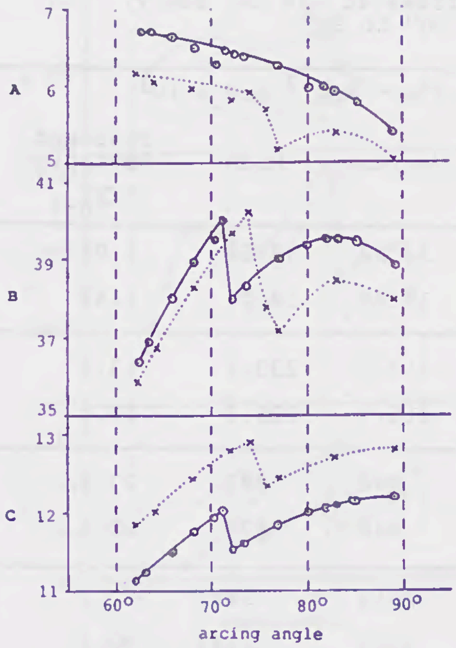


FIG.1 100A fuse

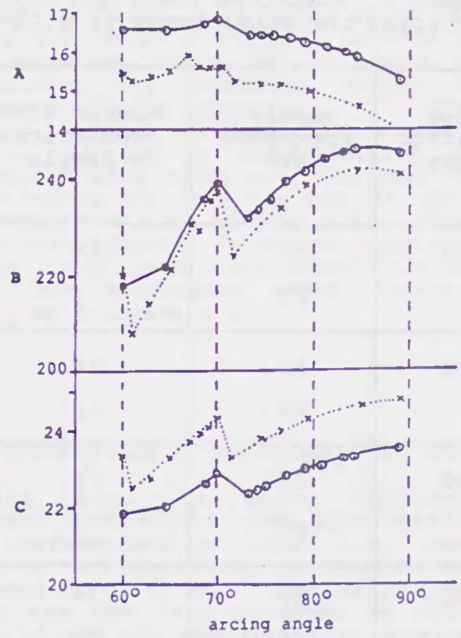


FIG.2 200A fuse

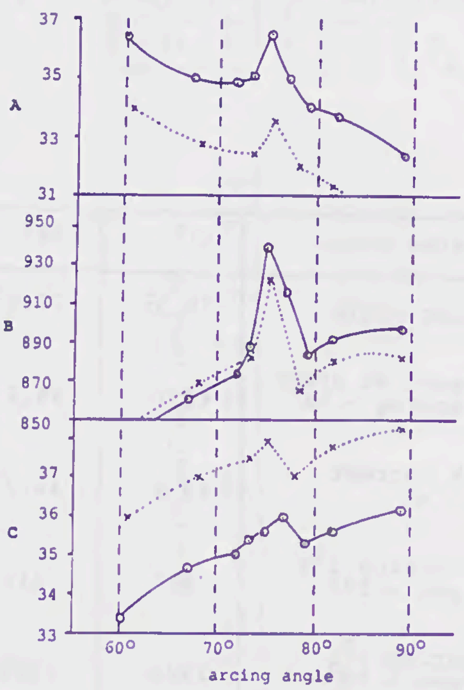


FIG. 3 400A fuse

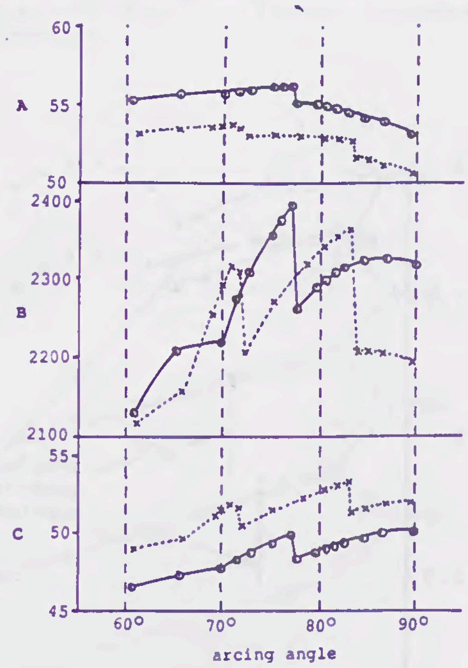


FIG.4 600A fuse

Key to FIGS. 1 to 4

—o—o—o 50 Hz data ···x······x······x 60 Hz data

A = Arc energy in kilojoules.

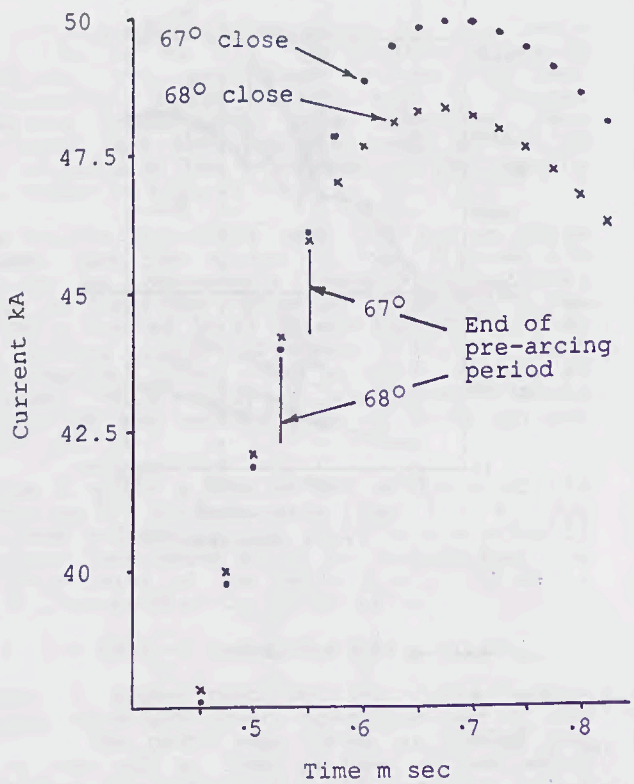
B = Clearing I^2t in A^2 sec x 10^3

C = Peak current (Ip) in kA.

FIGS. 1 to 4 Predictions for performances of HRC1-J fuses at 200 kA, 600 V, 0.11 p.f.

TABLE 2 Predicted total I2t values of HRC1-J fuses at 200 kA, 600 V, covering the whole range of arcing angles from 60° to 90°

Fuse Rating Amps	Supply Frequency Hz	Number of Predictions in Sample	Clearing I^2t - Amp ^{2} sec x 10^3			
			Maximum	Minimum	Mean	Standard Deviation σ_{n-1}
100	50	14	40.03	36.32	38.68	1.08
	60	9	40.49	35.88	38.04	1.42
200	50	14	245.6	217.2	233.2	13.8
	60	15	241.3	216.5	228.3	10.4
400	50	9	935	842	887	27.6
	60	7	921	848	878	22.6
600	50	17	2396	2019	2281	91.9
	60	17	2358	2023	2244	92.6



Closing angle	67°	68°
Arcing angle	76.9°	77.5°
Current at start of arcing - kA	46.1	44.2
Peak current kA	49.9	48.3
Pre-arcing I^2t A^2 sec x 10^3	387	340
Clearing I^2t A^2 sec x 10^3	2396	2265
Pre-arcing time-m sec	0.55	0.52

FIG.5 Predicted variations of fault current when the circuit is closed at 67° AND 68° to operate HRC1 - J 600 A fuses at 200 kA, 0.11 p.f., 600 V

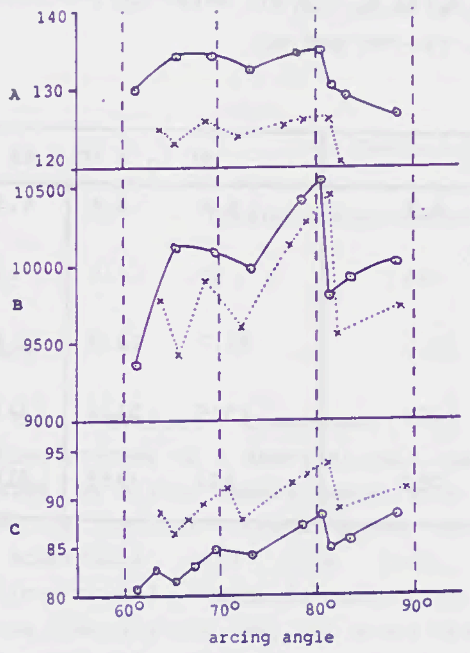


FIG.6 Predictions for performance of HRC11-C 600 A fuse at 200 kA, 600 V, 0.11 p.f. (Key as per Figs. 1 to 4)

3.1 Fault levels at 415 V, 400 Hz

A fault of 30 kA, 0.25 p.f., at 50 Hz would become 3.9 kA at 0.032 p.f. if this circuit were supplied from a 400 Hz source instead (neglecting any resulting change in the impedance of the source). If this same circuit then had its power factor modified to 0.9 at 50 Hz by the addition of the resistance of a cable run, the fault current would reduce to 13.5 kA, and at 400 Hz it would become 3.7 kA at 0.25 p.f. From these crude calculations, it can be concluded that 400 Hz fault levels are never likely to be high, but associated power factors will always be relatively low.

3.2 Predictions of performance at 400 Hz

Arising from the above considerations, computer predictions have been obtained for the performances of some l.v. industrial fuses at 415 V, 400 Hz, 0.05 p.f., at fault currents up to 40 kA. The results show that fuses are far less stressed at 400 Hz in terms of the arc energies they dissipate and the clearing I^2t values they produce. However, their peak current values are 60-80% greater than 50 Hz values at the same fault levels (with assumed power factors of 0.1 - 0.2 at 50 Hz). Figure 7 shows these differences.

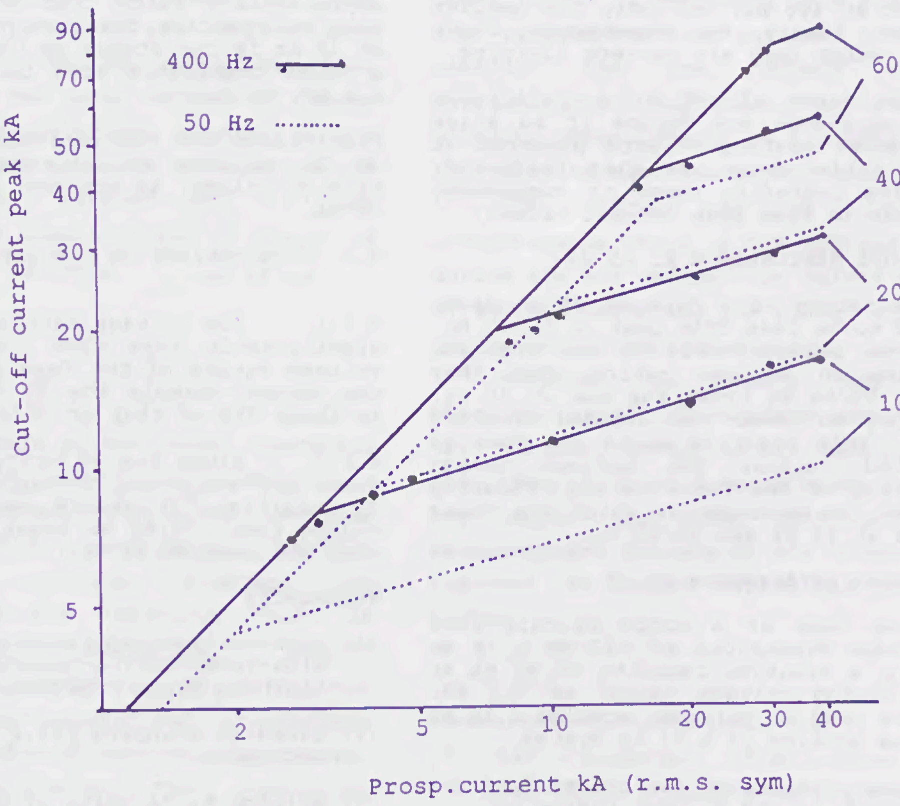


FIG.7 Cut-off current characteristics of l.v. industrial fuses to B.S.88-2 at 50 Hz and 400 Hz, 415 V

TABLE 3 Predictions of let through values for a 250 A, 7.2 kV, motor circuit fuse at the voltages and frequencies shown

	At I_1 = 46 kA			At I_2 = 20.7 kA		
Applied voltage (kV)	6.4	6.4	4.8	6.4	6.4	4.8
Frequency (Hz)	50	25	25	50	25	25
Peak current - I_p (kA)	29.4	23.4	22.1	21.7	20.3	15.6
Clearing I^2t (A^2 sec x 10^3)	2228	5052	1908	2366	5132	2321
Arc energy (kJ)	739	1429	753	832	1453	916

3.3 Observations on the application of fuses at 400 Hz

3.3.1 Fault levels are low compared with 50 Hz industrial values, and fuses easily cope with any fault conditions they are likely to encounter.

3.3.2 Fuses produce much larger values of peak current at 400 Hz, but only the smaller ratings are likely to experience fault currents at which they are current limiting.

3.3.3 Designers of 400 Hz installations use 50 Hz equipment and derate it to allow for the greater heating effects produced at 400 Hz. Cable sizes are also increased. This practice therefore tends to compensate for increases in fuse peak current values.

4. H.V. FUSE PERFORMANCE AT 25 Hz

The voltage rating of a fuse at 25 Hz might be expected to be less than that at 50/60 Hz. However, some manufacturers do not indicate any decrease in voltage rating when they offer their 50/60 Hz types for use at 25 Hz, although they do lower the claimed breaking capacity. This practice would not seem to be justified, unless the maximum design voltage rating of the fuses is significantly greater than the voltages at which the fuses are applied at 25 Hz and 50/60 Hz.

4.1 Predicted performance at 25 Hz

Consider the case of a motor circuit fuse with cartridge dimensions of 403 mm x 76 mm dia., having a breaking capacity of 45 kA at a maximum design voltage rating of 7.2 kV. This fuse is used at voltages down to 4.16 kV and might be applied in a 25 Hz system.

Table 3 gives predictions for the performance of this fuse at I_1 and I_2 when tested at 6.4 kV, 50 Hz (i.e., approximately 87% of 7.2 kV in accordance with IEC 282-1).

The I_2 duty stresses the fuse slightly more than the I_1 duty, and this accords with actual test data recorded on this type. The table also indicates the performances of this type when it is subjected to 6.4 kV and 4.8 kV, both at 25 Hz.

At 6.4 kV, 25 Hz, the stress on the fuse in terms of arc energy and clearing I^2t is approximately twice that at 6.4 kV, 50 Hz. Only by reducing the test voltage to 4.8 kV at 25 Hz is the stress on the fuse reduced to a level comparable with that encountered at 6.4 kV, 50 Hz.

Predictions for the performance of this type at 30 kA show no alleviation in the let through values, as compared with those at 46 kA.

4.2 Observations on the application of fuses at 25 Hz

4.2.1 The voltage rating at 25 Hz must be significantly less than the maximum design voltage rating of the fuse at 50/60 Hz. In the chosen example the 25 Hz voltage rating is about 75% of that at 50/60 Hz.

4.2.2 Since the majority of high voltage fuses are subjected to maximum stress at the I_2 condition, it should not be necessary to reduce their 50/60 Hz breaking capacity when they are used at 25 Hz.

REFERENCES

(1) Underwriters Laboratories Standard for High-Interrupting-Capacity Fuses, Current Limiting Types - UL198C.

(2) Canadian Standard C22.2 No.106 - M1985, HRC Fuses.

(3) Wilkins R: "A suite of interactive programs for fuse design and development" Int.Conf.on Electric Fuses and their applications, NTH, Trondheim, 13-15 June 1984, p.p. 227-235.