THOUGHTS ON FUSE OPERATION

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INTRODUCTION Nominally simple, the concept of series conductor piece desintegration under overcurrent influence in order to circuit interruption actually involves complex electrical, thermal and mechanical processes.

At present among different kinds of fuses one may distinquish the following operating principles:

i onefold fuses (OF),

ii permanent fuses (PE).

OF today are mainly: expulsion fuses (EF) and quartz-sand filler fuses, which commonly are called h.r.c. fuses.

PF, primary developed abt ten years ago in Japan[1], now are intensively improved in some other countries too. The explanation of fuse operation principles in case of PF therefore is now to early and because of that will be out of consideration in this paper. However, all the interested with PF may take aquaintance with papers[2,3] well introducing into actual state of the problem. There are some other papers and especially patents in the field of PF too.

Also EF will be omitted because normally they are not short--circuit current-limiting devices. The mode of EF operation shown in paper[4] is like many other a.c. current interrupting devices: they finally interrupt at some succesive naturally current zero passing. The arc-quenching process is here in large scale independent from thermal pre-arcing phenomena[5].

In contrary to EF h.r.c. fuses normally are current-limiting devices with arc-quenching process predicted by thermal pre-

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-arcing phenomena. That is the reason, why this paper gives some thoughts on h.r.c. fuse operation principles only.

During the decades prior to the second world war experimental and theoretical physics had gathered some basic knowledge on the interrupting process of h.r.c. fuses. However, there was a wide gap between the fundamental science and the possibility to apply the results of development in physics to the problem of interruption of high and low currunts under the conditions fuse have to operate.

25 year ago Baxter(6) published his well known book with more systematic fundamental laboratory tests results of h.r.c. fuses operation physics.

The last period gives many further fundamental results mainly for h.r.c. fuses with stripe fuse-elements, synthesized in book(7). Another polish book(8) and a recently edited one in U.K.(9) have the h.r.c. fuses applications for safety in electrical systems as their main subject.

Finally, the Läpple´s book(10) gives a critical review of published informations up to abt 1950 in the field of electric fuses, which are supplemented e.g. up to 1965 by ERA Report(11) and others.

Therefore the answer on the question 'how does a h.r.c. fuse really operates' now is much more easy than formerly.

In spite of that we are still far away to complete the knowledge concerning especially the fuse-element disrupting and arc-quenching processes. In close connection with these there are the thermal states of the fuse-element reached just prior its disrupting. These thermal states have not a fully explanation yet, especially in the case of deep notched fuse--elements.

In addition, this matter hase become more complicated due to new h.r.c. fuse design inventions*), which introduced in practice permanently modify the fuse-element disrupting and arc-quinching process.

That´s why in the following there only will be given some explanations for more or less simple and common cases.

SOME REMARKS ON H.R.C. FUSE OPERATION The temperature distribution along the fuse-element just prior its disintegration is the main predicting factor of the arc-ignition and arc-quenching processes.

Today the dimensions and material properties of fuse-link contacts and of fuse-link insulating tube are nearly these same for the same h.r.c. fuse size manufactured by several firms. Therefore for a given preloading state and for a given overcurrent the temperature distribution along the fuse-element greatly depends on longitudinal mode of its cross-section variation (Fig.1).

The h.r.c. fuse-elements may be divided as follows:

i Long or short, depending upon ratio L/D, where D-the outer diameter and L-the length of the fuse-link with given fuse element. It is called long with L/D> apprx.5 or short with L/D < apprx.5.

ii Uniform or notched cross-section.

iii With one stripe or one wire, with multi-stripe or multi-wire fuse-elements.

Because of the great thermal coupling between neck and shoulders of notched elements, by the steady state or by long time overloads the temperature differences along the fuse element are not significant (Fig.1 temperature distributions1). But for short-circuits the differences are very distinct (Fig.1 distributions2).

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*) e.g. during 1974 the number of established h.r.c. fuse patents in USA only is abt 50

The correct and faulty operation of a fuse by overloads and short-circuits may be investigated in idealized oscillograms (Fig.2, 3, 4, 5).

<u>Overload Current Interruption</u> Independently from correct or faulty operation (Fig. 2 and 3) there goes during period A a heating process of the whole fuse as a consequence of Joule's heat-emitting in fuse-element. These heat conditions may be calculated using corresponding equations or methods given e.g. by papers[12, 13, 14, 15].

The arc-ignition and arc-buring process depends from:

i shape of fuse-element,

ii value of overload current ratio to the rated current of the fuse-link.

There are possible the following arc mechanisms:

i one-arc,

ii multi-arc.

One-arc ignition will occur, if:

i Short fuse-link has uniform-section or multi-notched fuse-element, which all notches have this same cross-section (Fig.1a,b) or central notch has the minimum cross-section.

ii Long fuse-link has a central notch with minimum cross-section.

For a uniform-section short fuse-element there must be additionally a low-enough overcurrent value. E.g. in the case of 500 V fuses with 0,35 mm dia silver wire fuse-elements the one-arc ignition will occur with overcurrents up to 5 I_n and up to 8 I_n if the wire is Soft[16], where I_n - the rated current of the fuse. In all mentioned cases the arc ignites at the beginning in or near the centre of fuse-element.

For d.c. one-arc there exist a calculation method of overcurrent interruprion process parameters[17]. This method should be succesfully adopted for a.c. one-arc interruption.

For short or long multi-notched elements the next arcs may ignite later with time-lag dependent from the cross-section differences of said notches.

Figures 2 and 3 are typical for one-arc ignition and one-arc burning process. The notations u_a and u_i used in figures correspond to the arc-voltages and to arc-ignition or arc--extinction voltages appearing near each current-zero.

The arc-burning time-interval B ends in moment t_2 with final interruption (Fig.2) or in moment t_e with complete evaporation of fuse-element and the arc-flames ejection appearing through holes melted in fuse-link-contacts (Fig.3). Temperature T measured in the section, where the first arc-burning will occur and further in the cathode and anode spot of an arc.

It is interesting to note, that during period B there may occur an aperiodical component of current (the moment t_{ap}) introduced by sudden change of discharge resistance[18].

In long fuse-links with uniform-section fuse-element and in short fuse-links with overcurrents greater than mentioned before values 5 I_n or 8 I_n there occurs a multi-arc ignition and multi-arc burning process with unduloids formation.

A recently published paper makes clear, that unduloid formations on the wire is independent from the current[20]. Upon my opinion, the current mainly accelerates the whole process and keeps the more strict periodical disintegration module only.

During the period C for correctly operating fuse the remainded fulgurite becomes cool, but, if fuse operation is faulty, the fulgurite is growing till to current interruption by another device in that circuit.

<u>Short-Circuit Current Interruption</u> As said before, in-

dependently from correct or faulty operation (Fig.4 and 5), during period A there goes a heating process mainly of the fuse-element. The heat conditions are more close to an adiabatic one now and are very simple, if there are pure adiabatic. They are complicated enough, if a heat transfer from norched parts to shoulders may appear.

The short-circuit disintegration process of the fuse-element depends from their shape. In case of uniform-section there appears a striated mechanism, more subtly described by Nasiłowski [21] and by Hibner [22] for stripes.

In case of a notched fuse-element there are two disintegration possibilities: striated mechanism or an one-arc mechanism. If the notches are long enough, they disintegrate with striation. For very short and deep notches an one-arc mechanism appears. Normally in the last case most fuse--elements have many short notches with these same cross-sections periodically distributed along the stripe. Therefore the arcs will appear in all the notches simultaneously. Than the arcs will elongate till to the current interruption or till to arc-flames ejection through holes melted in fuse--link-contacts. Such faulty arc-quenching mechanism is not showed in the Fig.5.

Fig.5 correspondes to the fuse-link explosion during arc--burning period (moment t_e), as a result of pressure shock wave.

During the period C in a correctly operating fuse the fulgurite becomes cool. Its property are described in the paper [22]

All mentioned mechanisms are not yet fully investigated. In spite of that, we may calculate the peak arc-voltage U_a [22], the let-through current i_o [23] and reacently we got a method of voltage and current calculation during period B [24], if notches are deep and short.

We are at the beginning of exploration of problems concerning the pressure shock wave p. The pressure shock wave withstand of a fuse-link body is an important parameter deciding the successful short-circuit interruption.

Moreover, the post-arc conductivity of a fulgurite is a problem, which needs a better investigation. This problem was discussed before last war in Germany[25], and in spite of existing a new paper[26], there is an essential lack in fundamental scientific work.

FINAL REMARKS However in previous paragraph the more detailed explanations are given how does a h.r.c. fuse operate, the text valume now is large enough. So it is time to get some short final remarks.

Many aspects of h.r.c. fuse operation are omitted in the paper. E.g. there are not any remarks concerning: long and short-time ageing phenomena of fuse-elements[27, 28] voltage-current fuse-arc characteristics[29], arc-burning and arc-quinching phenomena for multi-wire and multi-stripe fuse-elements[30, 31], phenomena in arc-quinching medium[32, 33], behaviour of fuse-elements in LC circuit[34, 35] and so on.

All these and other questions should be involved during Conference discussion to get more precise answers how does really h.r.c. and other kinds of fuses operate.

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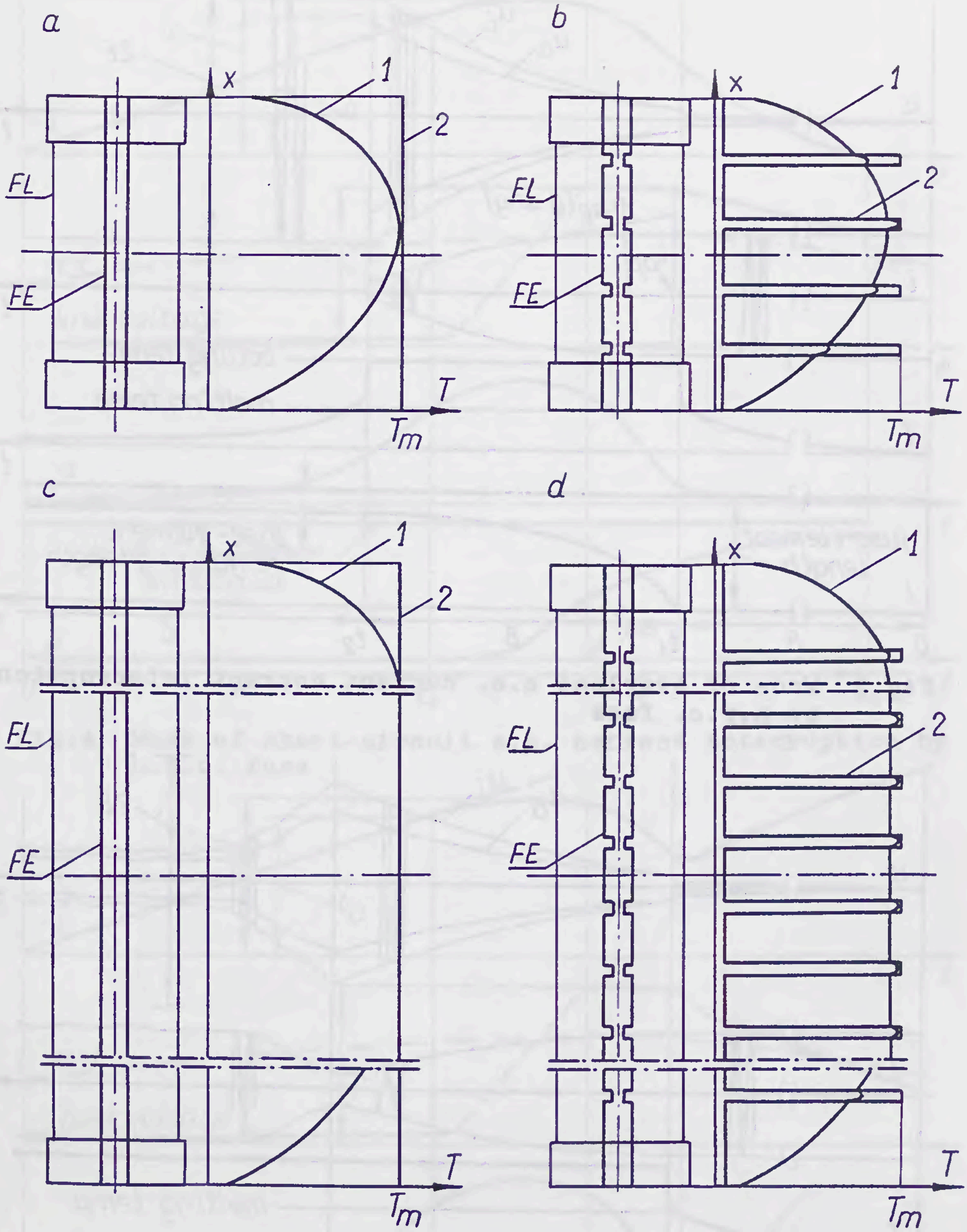

Fig.1 Idealized temperatur distributions from cool state just prior fuse-elements FE disintegrations along uniform section figures a and c and notched figures b and d fuse elements streached in the h.r.c. fuse links FL
1 - steaty state or long time overload heating,
2 - adiabatic short-circuit heating

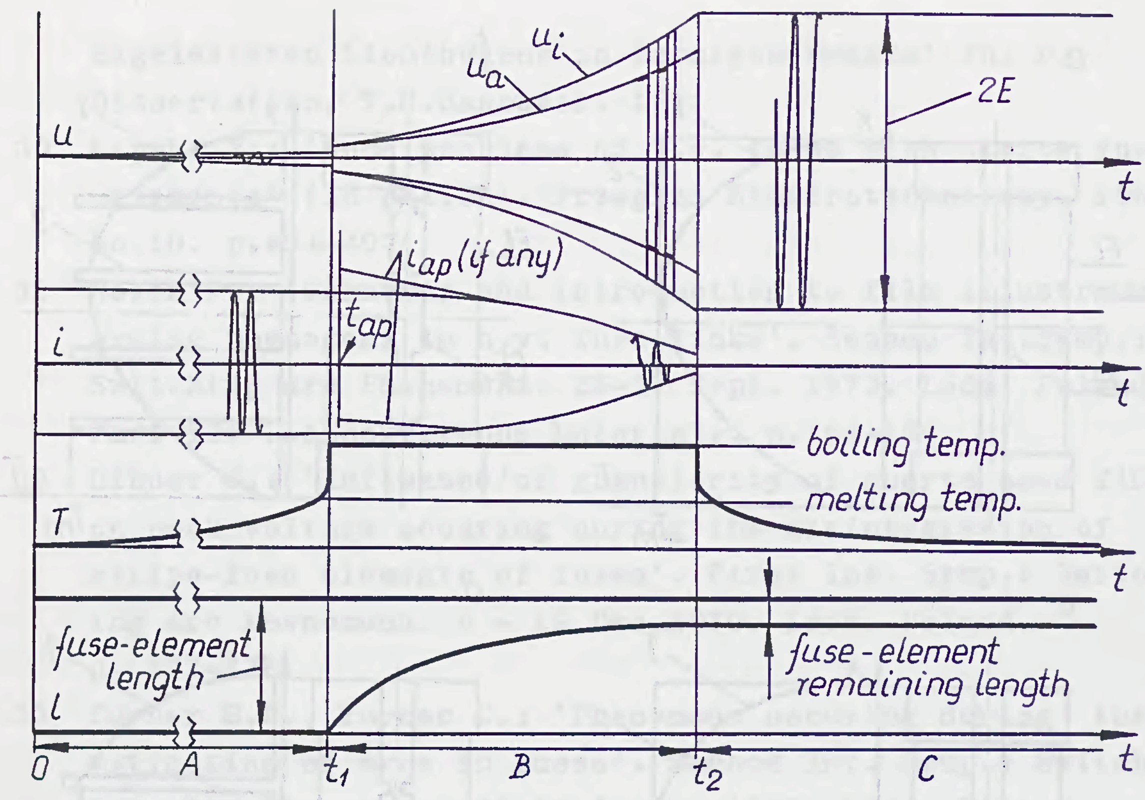

Fig.2 Mode of overload a.c. current correct interruption by h.r.c. fuse

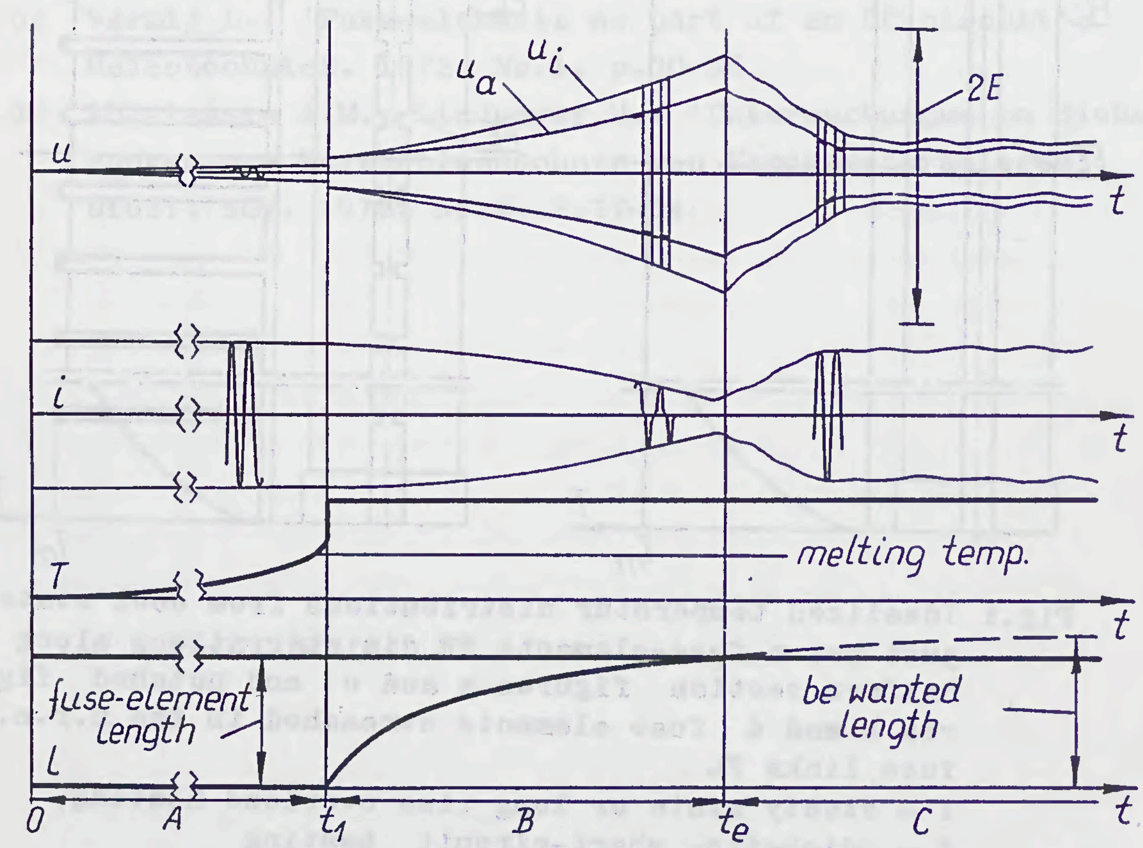

Fig.3 Mode of overload a.c. interruption by h.r.c. fuse with arc expulsion in moment t_e

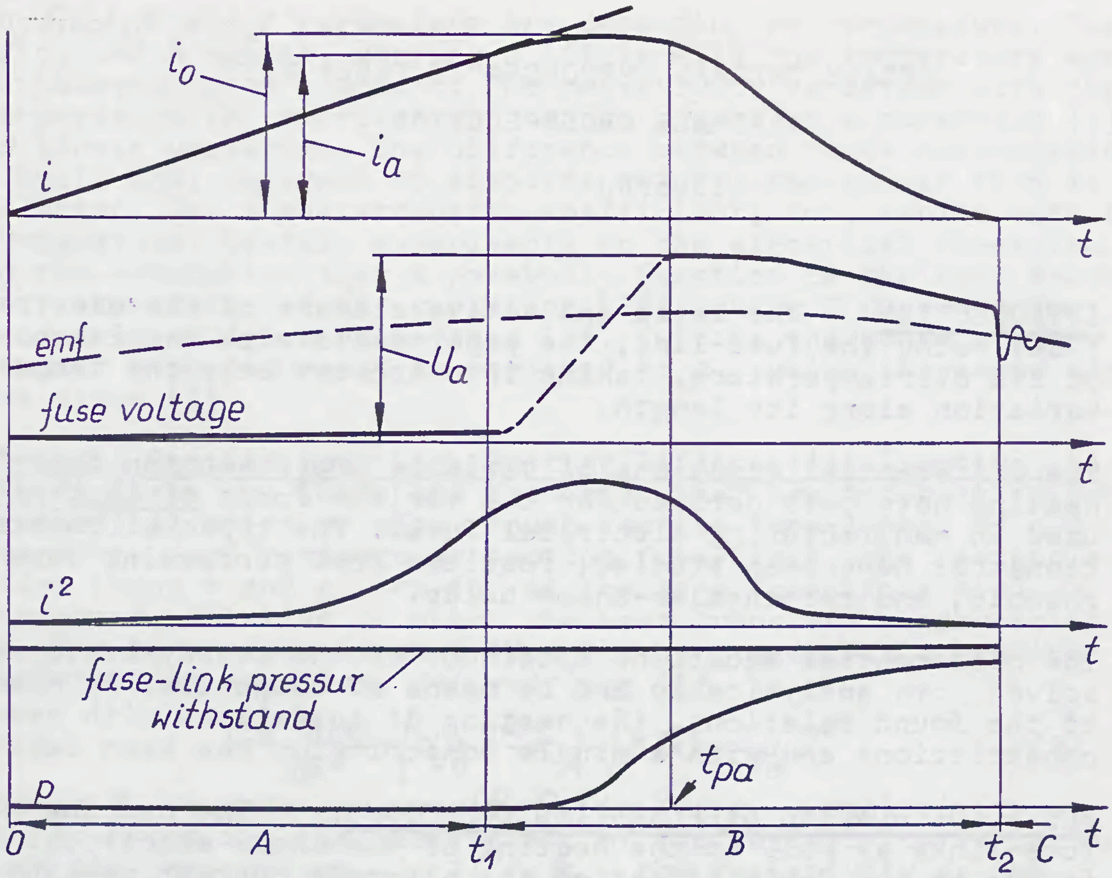

Fig.4 Mode of short-circuit a.c. correct interruption by h.r.c. fuse

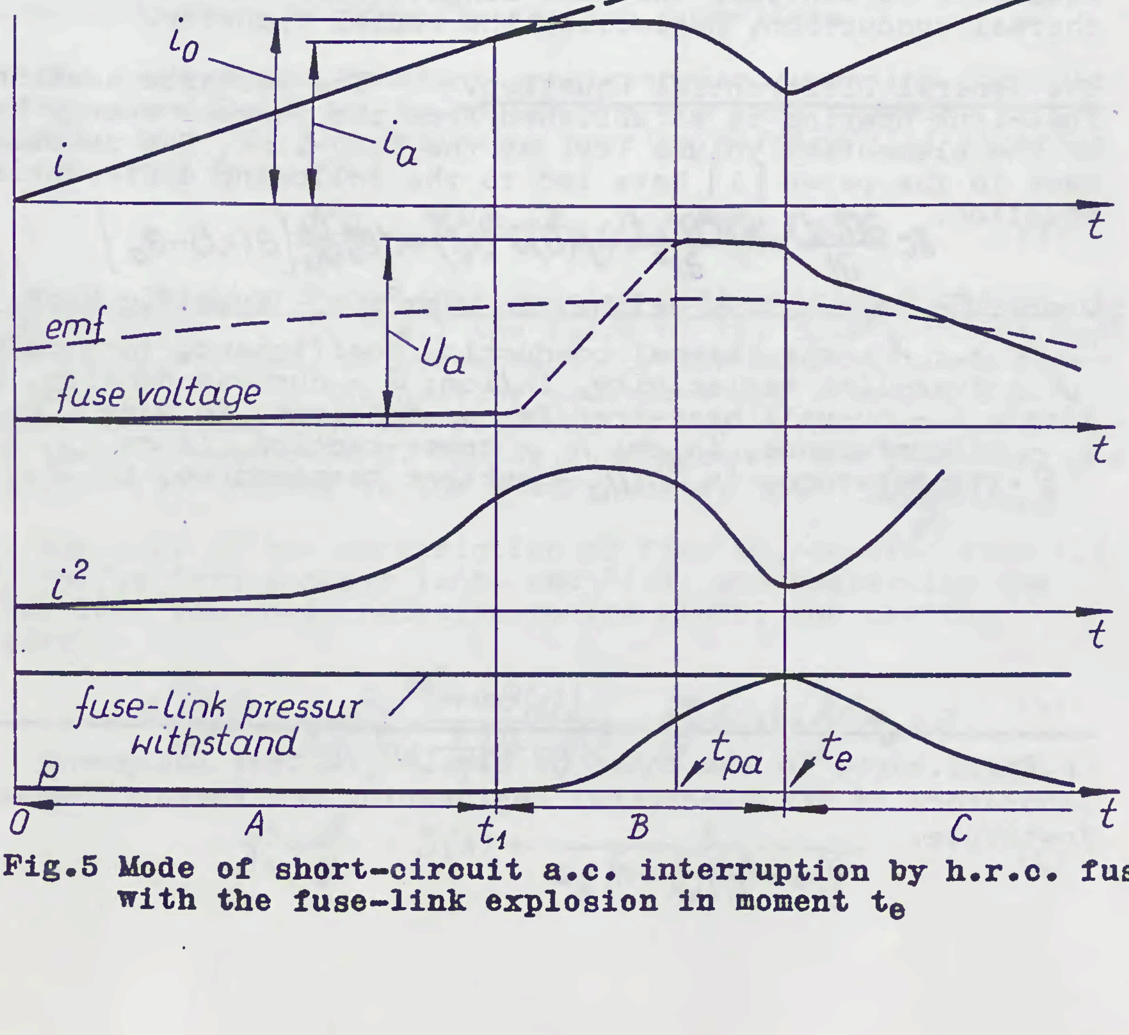

Fig.5 Mode of short-circuit a.c. interruption by h.r.c. fuse with the fuse-link explosion in moment t_e