# COMPARISON OF ELECTRICAL BEHAVIOUR BEETWEEN THE LIQUID METAL CURRENT LIMITER AND THE LOW VOLTAGE MELTING FUSE

**Mitja Koprivšek**

ETI Elektroelement d.d.,
Obrezija 5, SI-1411 Izlake, Slovenija,
mitja.koprivsek@eti.si

*Abstract:* **Liquid Metal Current Limiter (LMCL) is in previous literature shown as a possible way how to realize a protection device which can break the short circuit current for several times. This article analyses the behaviour of LMCL and his functional principles under short circuit current conditions. The main part of this article consists of analysis of electrical behaviour of a melting fuse and LMCL under same testing conditions. At the end, the conclusions are made regarding future research.**

*Keywords:* **Liquid Metal Current Limiter, Low Voltage melting fuse, short circuit current.**

## 1. Introduction

Switchgear devices in general are made for following functions:

- Distribution of electrical energy
- Control of electrical consumers
- Protection of people, animal and equipment against electrical shock

Main functions are:

- Connecting
- Switching
- Disconnecting

of circuits

To fulfil various demands, many different devices with main functions were developed. A lot of switching principles have been developed to fulfil demands from different switching processes.

From electro technical point of view, switching event is a process where impedance is changed for a large scale, e.g. from 1mΩ to 10MΩ in a time of milliseconds. This fact requires use of different switching principles according to different parameters of the circuit.

Switching devices, where the switching event is concluded with current zero within normal sinus wave, has no protective function. Protective function in such a case is connected with the capability of a device to reduce the thermal effect due to $I^2t$ let-through energy and dynamic effect due to the let-through current $I^2$ .

Switching devices with current limitation as protective function are:

- Circuit breakers
- Current limiters
- Fuses

It is true that not all Circuit breakers has current limitation properties. Those with “current zero” arc quenching principle cannot be counted in above mentioned switching devices. Nowadays, more and more circuit breakers are designed as current limiting devices. On the other hand fuses and current limiters has strong current limitation property

This article will show functional principles of Melting Fuses and Liquid Metal Current Limiter (LMCL) and comparison of electrical behaviour of Melting fuse and LMCL, where LMCL is self-restoring current limiter, with another words, LMCL has reproducible and repeatable current limitation behaviour.

## 2. Melting fuses, functional principles

Following Figure Fig1 shows a diagram of electrical behaviour of melting fuse under short circuit condition. It is known from the literature, that short circuit current limitation is provided by arc voltage, which is higher than network voltage. Melting and arcing phases are also clearly shown on Fig1 [1]

On one hand, the fuse is very economic and efficient short circuit protective device, on the other hand it has only one main disadvantage, namely, the fuse link has to be replaced by the maintenance crew and in the mean time this part of installation is without supply of energy. The question is, how to create a short circuit protection device, which is able to cut the short circuit fault current for several times without replacement. One of the possible answers is Liquid Metal Current Limiter.

 978-2-84516-363-8/07/$25.00 © 2007
Blaise Pascal Academic Press

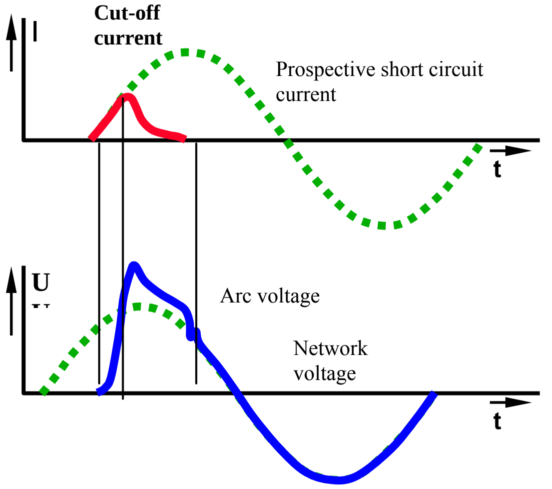



Fig 1: diagram of electrical behaviour of melting fuse under short circuit condition

## 3. Liquid Metal Current Limiter

Nowadays there is an increasing demand of use of electrical energy, especially in industrial sector. These demands are shown through the following criteria:

- Higher short circuit power available
- Higher system voltages (specially in industry)

On the other hand, a demand for selectivity has to be considered in case of several protective devices connected down stream in the installation. In case of an error, only the last protective device has to break the current. Thus, the higher availability level of an electrical energy is provided.

Another demand is more and more important in low voltage installation, and that is how to prevent the exhaust of hot gases out of the breaker. In the future, all switching devices, which are working on the principle of contacts, will have to be closed in housings. On the fig.2 above we can see the principle of LMCL, consisting from enclosure where liquid metal is separated with several spacers. In each spacer there is at least one spacer channel. On both ends there are electrodes and terminals for electrical connection of LMCL.

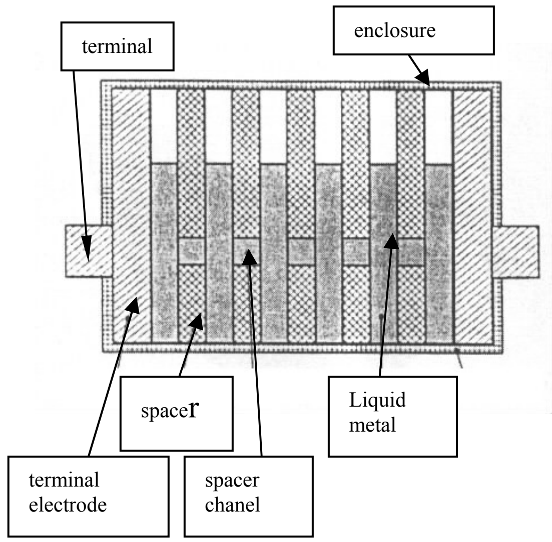



Fig 2: Construction of LMCL

### 3.1 Material behaviour and functional principle:

Liquid metal is very interesting conductive Gallium-Indium-Tin alloy (GaInSn). This alloy is non-toxic and is also used in various medical applications. In investigations [3] an eutectic alloy was used, with lowest melting point. The most important physical properties given at 20°C are shown in table 1.

Table 1: physical properties of GaInSn alloy

| | | |
|---|---|---|
| Melting point | $\vartheta_M$ | 10.5°C |
| Boiling point | $\vartheta_E$ | > 2000°C |
| Density | $\rho$ | 6.4 g/cm$^3$ |
| Electrical conductivity | $\sigma$ | 3571($\Omega$ mm)$^{-1}$ |
| Thermal coefficient (el.) | $\alpha$ | 0.00088 K$^{-1}$ |
| Specific heat capacity | $c$ | 320 J/kgK |
| Heat of evaporation | $h_E$ | 3337 kJ/kg |
| Thermal conductivity | $\lambda$ | 35 W/mK |

**»Self pinch-off« effect** is a consequence of electromagnetic forces in liquid metal. Usually, it appears between contacts in classical switchgear devices when contact material is melted. The cause of pinch effect is geometrical instability of magnetic field. This instability in LMCL, is caused by spacers and spacer channels. Fig 3 shows the current density and magnetic field instability. The model on Fig 3 is described in [5].


978-2-84516-363-8/07/$25.00 © 2007
Blaise Pascal Academic Press

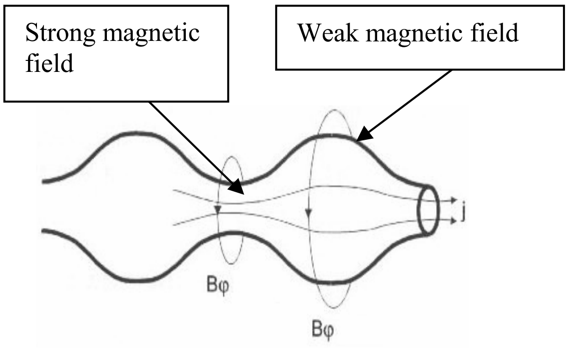



Fig 3. Geometrically unstable magnetic field

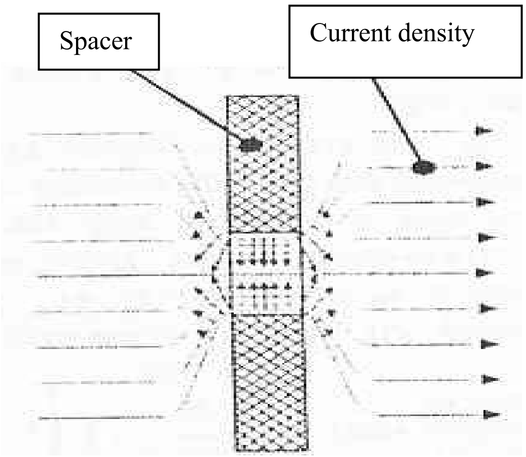



Fig 4. Pinching of liquid metal

Fig 4 shows one spacer channel and direction of magnetic forces, which are the cause of to liquid metal separation and arc ignition [2]. According to [3] the highest pressure is in the axis of the channel. In [5] following equation is presented:

$$p(r) = \mu_0 \frac{I^2}{4\pi^2 r^2}\left[1-\left(\frac{r}{R}\right)^2\right] \qquad (1)$$

Where

$p(r)$: Is pressure in liquid metal related to the radius in the channel

$R$: Radius of the channel

# 4. Comparison of electrical behaviour between the low voltage melting fuse and the LMCL

First of all, the construction of both devices was compared.

## 4.1. Comparison of construction features:

A construction of LV melting fuses type NH00 with rated current 100A and some data are presented in [4].

Current densitv

- Melting element NH00 100A
  - Copper strip: width=18mm, thickness=0.18mm, cross-section = 3.24mm$^2$
  - Length: 38mm
  - Constriction: width=2.4mm, thickness=0.18mm, cross-section=0.432mm$^2$
  - Length of each constriction: 2.0 mm
  - Cross-section ratio between melting element and constriction: 3.24/0.432= 7.5: 1
  - Number of constrictions: 5
  - Specific conductivity of basic material: E-Cu: 58 (m/Ωmm$^2$)

- LMCL:
  - In [3] the number 15 of spacer channels are recognized. The contribution to arc voltage is given only by 6 or 7 spacer channels which can be compared with constrictions on melting element.
  - Ratio between spacer channel and the rest of current path in LMCL: 7: 1 [2]
  - Exact dimensions of LMCL are not presented.
  - Resistance of LMCL before the test is not presented in the literature.

- Comparison of conductivity and dimensions between the melting element of the fuse and the LMCL:
  - Comparison of conductivity:
    - Specific conductivity of copper: 58000 $(\Omega\mathrm{mm})^{-1}$
    - conductivity of copper is 16.2 greater than GaInSn alloy,
    - specific conductivity of GaInSn alloy: 3571 $(\Omega\mathrm{mm})^{-1}$

Comparison of melting fuse and LMCL shows very good similarity of both constructions, especially in ratio of constriction and normal current path.


978-2-84516-363-8/07/$25.00 © 2007
Blaise Pascal Academic Press

### 4.2 Comparison of pre-arcing process in melting fuse and LMCL:

**Melting Fuse**: Pre-arcing time depends on quantity of thermal energy $I^2t$, caused by the current through the melting element. It also depends on the construction of constriction and material behaviour, namely, on melting point.

**LMCL**: From literature [3] it is known that the pressure in liquid metal depends on $I^2$. In the same literature the time for liquid metal separation is also calculated. In principle, this pre-arcing time can be compared with melting time in fuses. It is estimated that the pre-arcing time in LMCL depends also viscosity of the liquid metal, especially at high currents where the liquid metal flow speed is higher. It is also estimated that the pre-arcing time depends on the pressure in the volume between the liquid metal and the enclosure (see Fig.2)

### 4.3. Diagram of short circuit breaking in LMCL [2]:

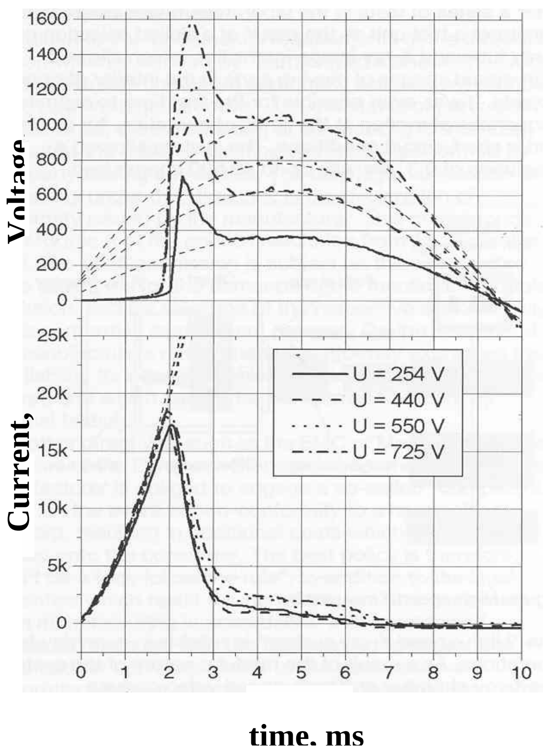


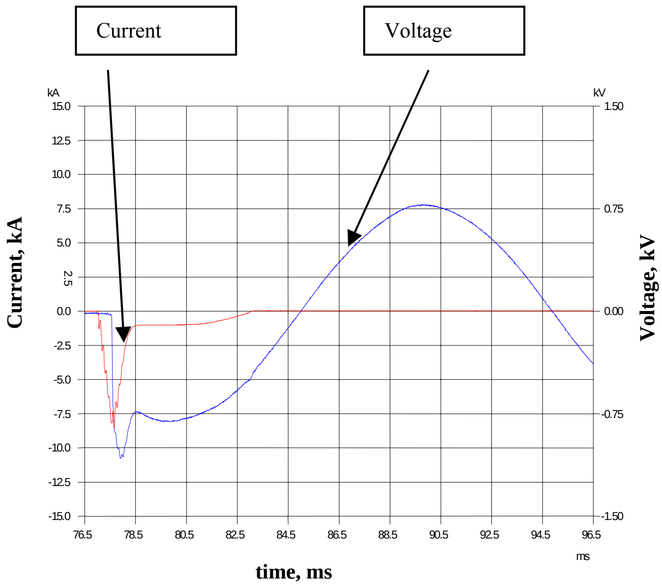

Fig 5: Diagram for voltage and current in LMCL

Testing Voltage $Up$= 550 V
Prospective short circuit current $Ip$=50000 A
Cos fi: 0.22
Switching angle according to voltage: 5°
Let-through current $Id$: 16.000 A
Arc Voltage $Uobl$ : 1.200 V
Pre-arcing time: 1.8 ms

### 4.4.Diagramm of short circuit breaking in Low Voltage melting fuse type NH00 [4]:

Testing voltage Up= 554V
Prospective short circuit current Ip=50500A
Cos fi: 0.18
Switching angle: 0°
Let-through current Id: 8.200A
Arc Voltage Uobl : 1.050V
Melting time: 0.6 msek
Other data:
- Resistance in cold status: 1.2 mΩ
- melting integral: 6.870 $A^2s$
- switching integral: 24.460 $A^2s$

Comparison of both diagrams on Fig 5 and Fig6 shows that the pre-arcing time in LMCL is longer than the one at the fuse.




### 4.5. Comparison of an arc phase in melting fuse and LMCL:

**Melting fuse:** from the literature the process of melting the copper strip is known. For the comparison with LMCL is important that also in the case of melting fuse Pinch-effect is mentioned as a cause for putting the melted metal apart which is followed by an arc. Metal vapours are present in the arc channel only for a very short time. Very soon arc channel is filled with silica sand vapours. Silica sand has lower point of evaporation than the copper. Arc


978-2-84516-363-8/07/$25.00 © 2007
Blaise Pascal Academic Press

plasma in the rest of arcing phase has the properties defined by $SiO_2$ vapours.

LMCL: in the literature there is no data about the heat transportation process to the surrounding and the cooling of an arc. But it is clear that in the LMCL liquid metal has also the role of cooling media. Arc channel is filled mainly with metal vapours [3].

## 5. Conclusions:

As a conclusion of presented work we can say the following:

- Electrical behaviour, that means current and voltage during the short circuit breaking in LMCL and melting fuse, are very similar at the same testing conditions,
- Presented comparison leads us to a conclusion that at further investigation on LMCL, experience from melting fuses could be used,
- There is no commercial product based on GaInSn alloy as liquid metal reported.
- GaInSn alloy as liquid conductor probably has no future in commercial use because of its price,

In low voltage switchgear technique laws of magnetohydrodinamics are used. One of the possible ways in future research could be serial connection of LMCL and LV breakers, where instead of liquid metal, other material, for instance materials on basis of nanotechnologies could be used.

## References:

[1] Mitja Koprivšek, Magistrsko delo, Univerza v Mariboru, marec 2005,

[2]A.Kraetzschmar, F.Berger, P.Terhoeven, S.Rolle:*Liquid Metal Current Limiters,* Moeller Gmbh, Bonn,

[3]F.Berger, O.Duehr.A.Kraetzschmar, P.Terhoeven: Physical Effects and Arc Characteristics of Liquid Metal Current Limiters, Moeller Gmbh, Bonn.

[4] Technical data and test reports, ETI d.d., Izlake, 2003 - 2004.

[5] F.Cap, *Lehrbuch der Plasmaphysik und Magnetohydrodynamik*, Springer Verlag 1994, stran 161.


978-2-84516-363-8/07/$25.00 © 2007
Blaise Pascal Academic Press