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# HARMONIC INSTABILITY IN CHANNEL INDUCTION FURNACES INDUCED BY STATIC CONVERTERS

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ABSTRACT. This paper presents the analysis and proposed solution of a harmonic instability problem in a casting plant. Current harmonics, generated by the rectifier of a coreless induction furnace, cause disturbances in a channel induction furnace (CIF) circuit. A system analysis has been done, based on a model developed for the system, through digital simulation of a dedicated program. The results were further compared to the measurements obtained from the plant. A simple and economic solution is proposed consisting in the inclusion of inductors in the capacitive branches of the channel induction furnace circuit. When this solution was implemented, system behavior and measurements showed that the solution was effective.

Keywords. Induction furnaces; harmonic instability; circuit modelling; power filters; power electronics

## INTRODUCTION

This paper describes the start-up experience of a 500kW @ 60 Hz channel induction furnace (CIF), which constituted a duplex installation with a 750 kW @ 1 kHz coreless induction furnace, already operating in the foundry.

The duplex procedure uses the CIF to keep the metal, previously melted in a coreless induction furnace, in the liquid state. This procedure increases the plant productivity, allowing a better analysis and correction of the alloys, by keeping casting and melting sectors operations independent.

The joint operation of these two types of furnaces is often employed in casting plants. Nonetheless harmonic instability problems arise in the CIF balance circuit, due to the coreless furnace controlled rectifier harmonics.

The casting plant described here is located at the end of a 13.8 kV distribution line. Due to the limited short circuit capability, the relatively high system impedance keeps the harmonic current circulation within the plant.

## THE PROBLEM

Channel induction furnaces (CIF) have a primary winding, a ferromagnetic core and their secondary winding is constituted by a closed ring of melted metal. They operate at mains frequency and represent a single phase low power factor load.

As shown in figure. 1, a balance circuit is employed both to feed the CIF from a three phase supply and to perform power factor correction. Channel diameter varies as a function of refractory material wear, resulting in line currents asymmetry. Then capacitors and inductor in the balance circuit may be adjusted, permitting to adapt the system to load parameters variation.

In figure 2 the plant schematic diagram is shown, with relevant parameters.

The rectifier feeding the coreless furnace absorbs heavily distorted non-sinusoidal currents from mains supply. Since the balance circuit capacitive branches offer a low impedance path for the higher order harmonic currents, and due to the supply low short circuit capability, harmonics are confined within the plant, causing damage in power factor capacitors elsewhere in the foundry. This is the problem to be corrected.

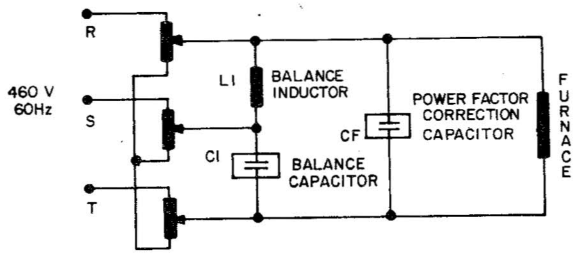

Fig. 1: Balance circuit of a channel induction furnace (CIF)

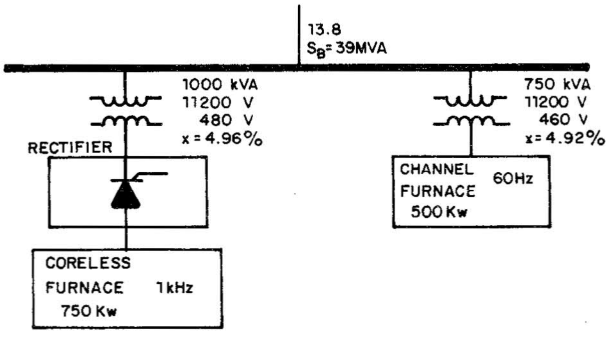

Fig. 2: Installation schematic diagram

In order to solve this problem, it was intended to reduce harmonic amplification by altering the natural frequency of low impedance paths. An easy and economic solution turned out to be the insertion of inductors in series with the capacitive branches of the CIF's balance circuit, as shown in figure 3.

## SOLUTION METHODOLOGY

In order to evaluate the adopted solution performance, without actual experimenting, an electric model and a dedicated program for digital simulation was developed.

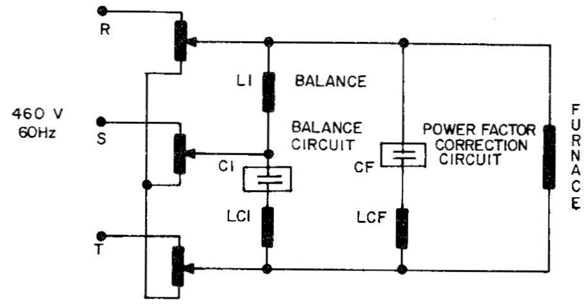

Fig. 3: CIF circuit with inductive filters

Measurements at the plant where made to obtain the plant electrical parameters for the model.

The coreless furnace controlled rectifier was modelled as a current source for each harmonic of order 6n±1, where n is an integer number. Figure 4 presents the equivalent circuit per phase, showing the harmonic current generators (IHARMn), the equivalent line impedance (ZLINE) and the CIF's circuit equivalent impedance (ZCIF).

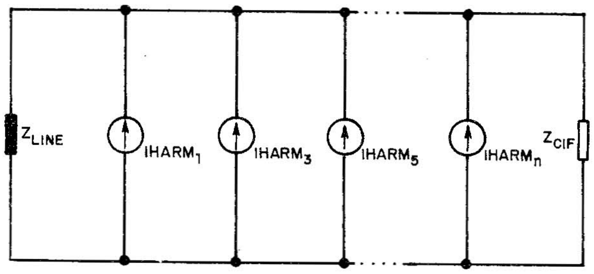

Fig. 4: Installation equivalent circuit

From rectifier line currents oscillograph records, firing and commutation angles were determined in order to evaluate the equivalent line impedance. These parameters were determined at full load, since they change with load. Parameter evaluation had to be done without disturbing normal production. The CIF's transformer reactance and balance circuit parameters were obtained from name plate data. The model adopted is shown in Figure 5.

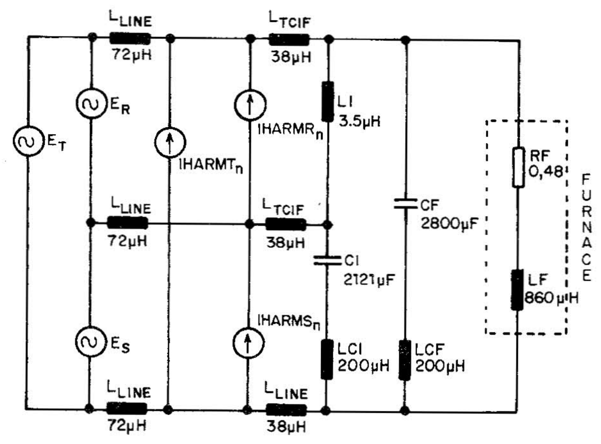

Fig. 5: Installation electric model.

Inductors were modeled as non-linear inductances as a function of current. Core saturation has considerable influence over line currents waveform, especially during transients.

This model allowed to write a finite difference equations system which could be simulated by a step by step procedure even in a personal computer. The software was written in order to show the transient behavior. It also permits parameters variation during the simulation. In order to avoid convergence problems, time steps not larger than 50 μs were utilized.

Table 1 shows CIF's RMS fundamental line currents, with and without inductive filters, obtained from the simulations. Table 2 shows CIF's percentage line current harmonic contents.

| CURRENT | WITHOUT INDUCTIVE FILTERS ( A ) | WITH INDUCTIVE FILTERS ( A ) |
|---|---|---|
| PHASE R | 282 | 295 |
| PHASE S | 309 | 308 |
| PHASE T | 344 | 274 |

Table 1: CIF's RMS fundamental line currents

| HARMONICS | | WITHOUT INDUCTIVE FILTERS ( % ) | WITH INDUCTIVE FILTERS ( % ) |
|---|---|---|---|
| 3. | PHASE R | 12.3 | 8.9 |
| | PHASE S | 5.6 | 9.9 |
| | PHASE T | 21.2 | 5.7 |
| 5. | PHASE R | 20.6 | 7.9 |
| | PHASE S | 23.5 | 4.6 |
| | PHASE T | 51.4 | 5.6 |
| 7. | PHASE R | 11.6 | 1.4 |
| | PHASE S | 9.7 | 1.3 |
| | PHASE T | 5.1 | 2.0 |
| 9. | PHASE R | 1.2 | 0.5 |
| | PHASE S | 2.3 | 0.9 |
| | PHASE T | 0.9 | 0.3 |
| 11. | PHASE R | 5.3 | 0.7 |
| | PHASE S | 7.8 | 0.6 |
| | PHASE T | 4.6 | 2.1 |
| 13. | PHASE R | 5.0 | 0.6 |
| | PHASE S | 2.5 | 0.6 |
| | PHASE T | 7.7 | 0.8 |
| 15. | PHASE R | 1.0 | 0.2 |
| | PHASE S | 2.9 | 0.3 |
| | PHASE T | 1.2 | 0.2 |
| 17. | PHASE R | 2.5 | 0.3 |
| | PHASE S | 5.3 | 0.5 |
| | PHASE T | 4.9 | 0.4 |

TABLE 2: CIF's percentage line current harmonic contents

Line currents without inductive filters are shown in figures 6a, 6b and 6c (one oscillogram per phase); the corresponding simulated waveform are shown in figures 6d, 6e and 6f. Heavy harmonic distortion is clearly noticeable.

## RESULTS

When inductive filters are introduced, line currents appear as shown in figures 7a, 7b and 7c (one oscillogram per phase); the corresponding waveforms obtained by simulation appear in figures 7d, 7e and 7f.

The implemented solution is simple and effective, reducing the harmonic levels, permitting safe system operation at low cost

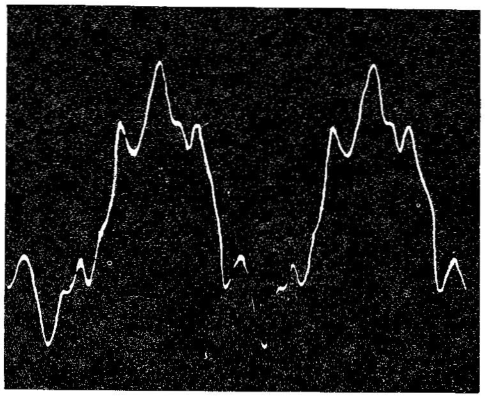

Fig. 6a: Oscillogram of phase R current, with neither inductor $L_{c1}$ nor $L_{CF}$.

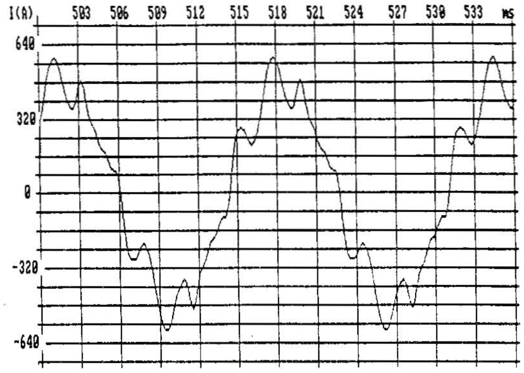

Fig. 6d: Simulated waveform of phase R current, with neither inductor $L_{c1}$ nor $L_{CF}$.

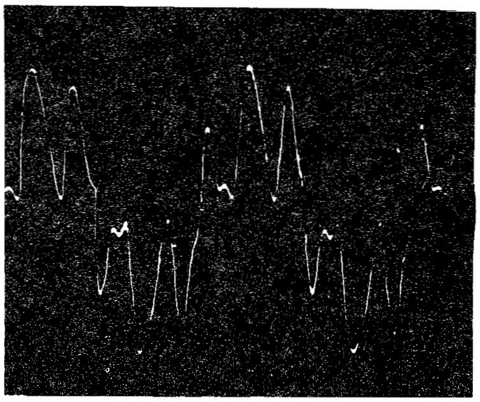

Fig. 6b: Oscillogram of phase S current, with neither inductor $L_{c1}$ nor $L_{CF}$.

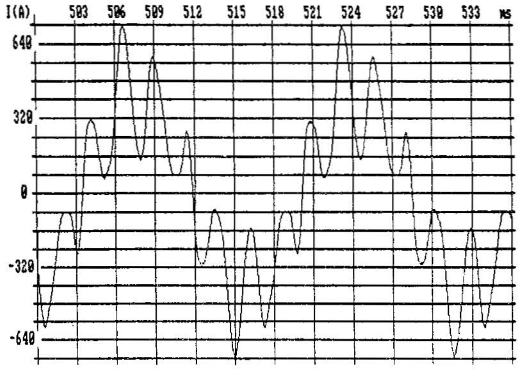

Fig. 6e: Simulated waveform of phase S current, with neither inductor $L_{c1}$ nor $L_{CF}$.

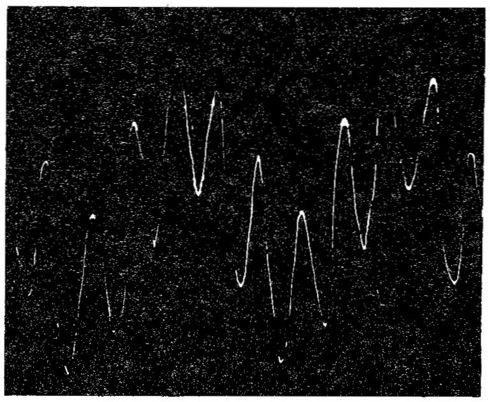

Fig. 6c: Oscillogram of phase T current, with neither inductor $L_{c1}$ nor $L_{CF}$.

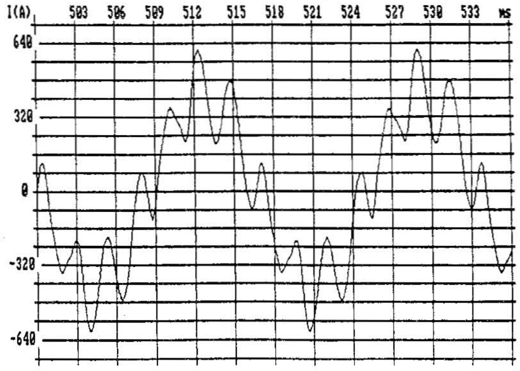

Fig. 6f: Simulated waveform of phase T current, with neither inductor $L_{c1}$ nor $L_{CF}$.

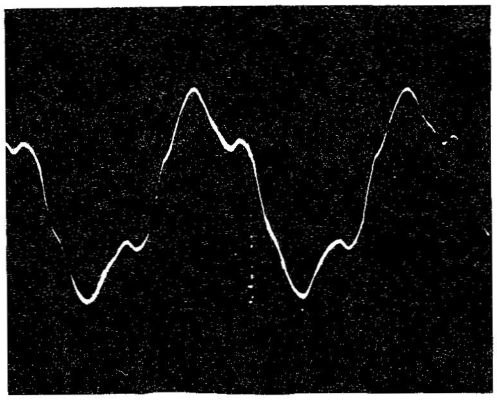

Fig. 7a: Oscillogram of phase R current, with inductors $L_{C1}$ and $L_{CF}$.

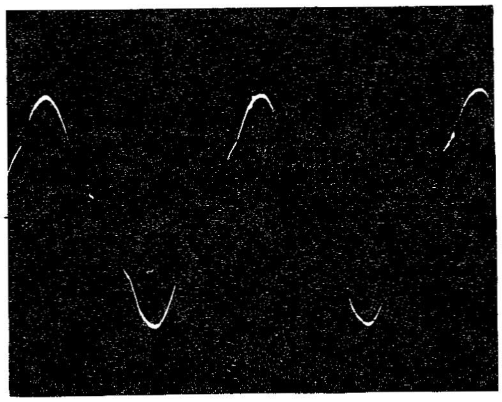

Fig. 7b: Oscillogram of phase S current, with inductors $L_{C1}$ and $L_{CF}$.

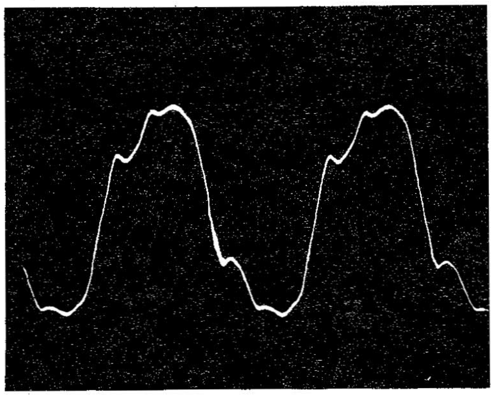

Fig. 7c: Oscillogram of phase T current, with inductors $L_{C1}$ and $L_{CF}$.

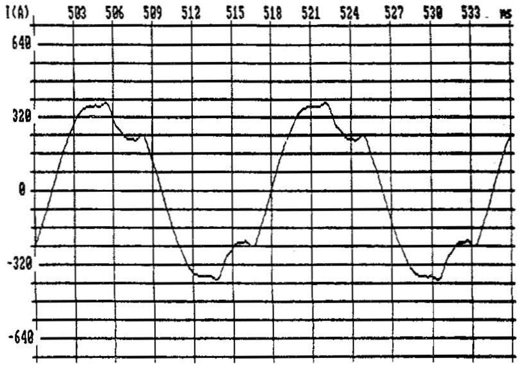

Fig. 7d: Simulated waveform of phase R current, with inductors $L_{C1}$ and $L_{CF}$.

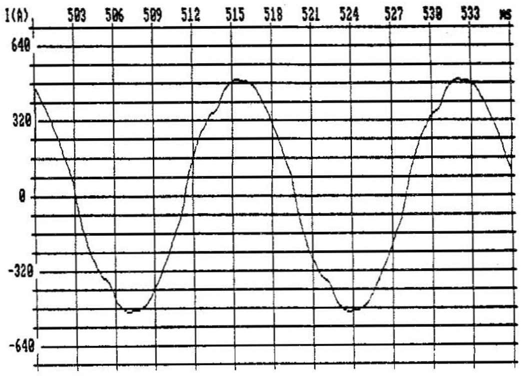

Fig. 7e: Simulated waveform of phase S current, with inductors $L_{C1}$ and $L_{CF}$.

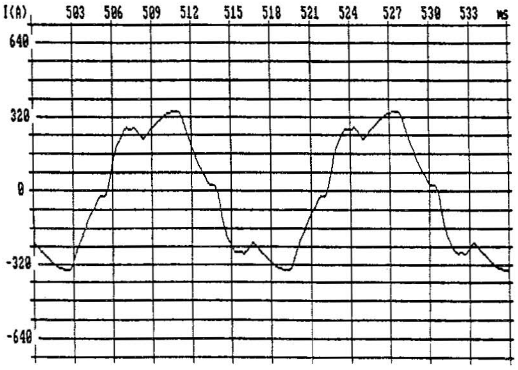

Fig. 7f: Simulated waveform of phase T current, with inductors $L_{C1}$ and $L_{CF}$.

and reducing the harmonic power filters installation cost at the plant power substation.

The differences between measured and simulated line currents waveforms are a consequence of uncertainties with values of the CIF's model parameters.

The required inductances values resulted to be low, and water cooling availability allowed compact and low cost inductors assembly, by using ordinary laminated ferromagnetic core and hollow copper conductors. The assembled inductors occupied volume in the CIF's panel resulted small.

## CONCLUSION

This paper presents the practical experience of a channel induction furnace start up in a foundry, where a harmonic generating coreless induction furnace was already in operation.

A digital simulation model was performed to obtain a low cost solution. This solution consists of inductive filters installed in the CIF's balance circuit capacitive branches in order to attenuate the effects of harmonic amplification in line currents.

The solution solved technical, economical, commercial and schedule aspects of the problem by letting the installation to go into operation. The results obtained have been considered satisfactory, showing that the system model as implemented offered a good representation of the actual physical circuit.

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