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BROSZ AND ASSOCIATES

ELECTRICAL POWER SYSTEM ENGINEERING & TECHNICAL FIELD SPECIALISTS
INTERNATIONAL FORENSIC ENGINEERS

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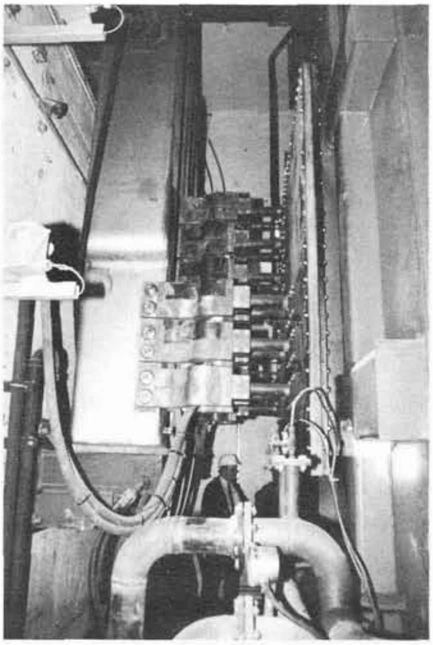
ARC FURNACE TRANSFORMER FAILURES



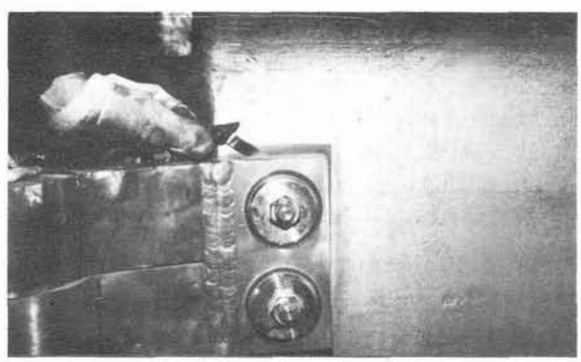
10,000 AMP Connections: Overheating on secondary (750V) side.

The electrical and mechanical duties imposed on transformers used in electrical arc furnace installations can be very exacting. The techniques of the operation and the unusual loads they produce are so severe, particularly on the transformer, that special design requirements and later, the maintenance of the units is essential. Recent examples of arc furnace transformer failures illustrate that it is possible in many instances for a forensic engineer to investigate and determine causes of failure, provided sufficient evidence is left.

An arc furnace is primarily used for converting scrap metal pieces to reusable material. The scrap metal is loaded into a refractory lined bowl and subjected to an intense electric arc generated between moveable electrodes and the scrap material. Until the scrap material is reduced to a molten mass, the electrical loads imposed on the supply are severe and erratic. The melting process can typically require up to 100,000 Amps of electric current which will have superimposed on it, harmonic variations, which are wildly fluctuating, causing very unusual load patterns in the supplying transformer. This means that the arc furnace must have a supplying transformer which is custom designed to meet erratic loads for what will effectively be the equivalent of many short circuits.

The rough behaviour produced by a vast succession of short circuits can be made even worse by mistreatment by the operator. For instance, when closing down the furnace it should be normal practice to raise the electrodes first. Some operators will simply trip the control circuit breaker resulting in considerable mechanical stress on the transformers. In fact, many problems in arc furnace transformers can be traced to mechanical failures. Some of the failure analysis work on arc furnace transformers done by Brosz and Associates illustrate such problems as well as difficulties associated with overheating.

(Please see over)



Close-up view of a defective 10,000 AMP bus connection. Note: Feeler gauge between mating surfaces.

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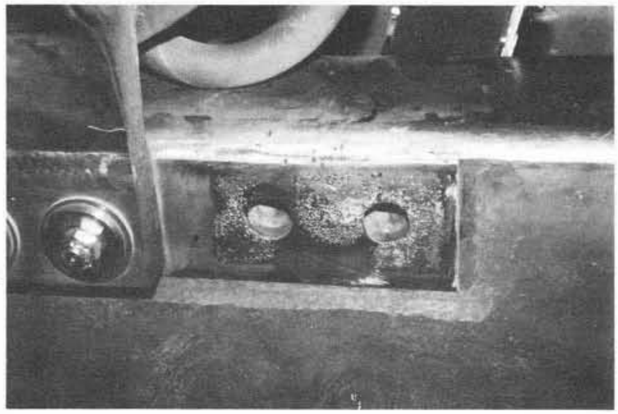
CASE I

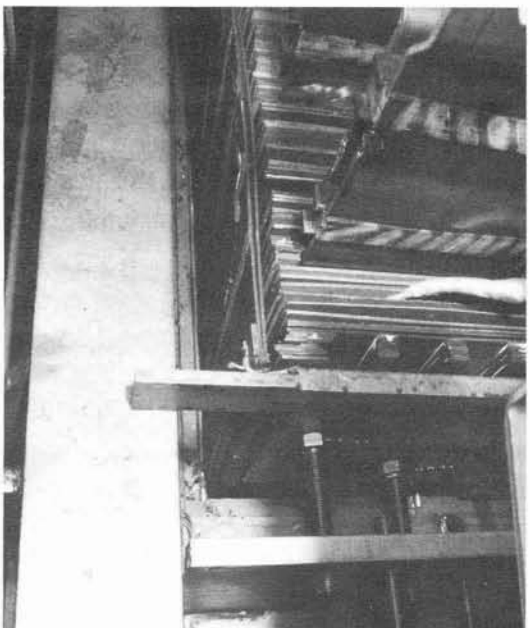
On a particular 60,000 Amp, 750V, 50 Hz arc furnace unit the high current main connections to the furnace were found to have gaps between the connections.

Severe burning and pitting found at 10,000 Amp rated connections was evidence of extreme heat. A feeler gauge could be pushed between the connection surfaces. The heat necessary to produce such pitting and burning had to be extremely high. This heat would be transferred to the transformer windings producing higher than normal temperatures in the winding and oil. This with the eccentric duty of the system combined to cause hot spots within the unit. Hot spots may lead to the deterioration of the insulation around the windings and sludging and the production of other contamination in the insulating oil.



Close-up view of deteriorated/overheated 10,000 AMP water-cooled connection.

Insulation failure, whether in solids or liquids will lead eventually to total failure and the loss of the unit. The lesson here is that all current connections must have maximum surface contact and run cool. Keeping highly fluctuating and sometimes severe overcurrent conditions within acceptable temperature limits will make insulation preservation easier. Installation checks to ensure good contacts added to knowledgeable preventive maintenance work, should aim for these requirements.



Shell form furnace transformer with loose core and shorted high voltage turns.

CASE II

In another case, where the furnace transformer was designed using a shell form configuration, failure was due to the inability to control short circuit forces. This is unusual since shell form designs are always believed to be mechanically stronger than core form designs.

Shell form transformer windings are considered easier to clamp and hold down during short circuit behaviour, but in this case the internal clamps loosened and did not hold and typical short circuit winding failures were found in the windings (see photo). Of course, the failure could have been due to extreme conditions within the general arc furnace circuit such as inadequate reactance, but, nevertheless, the evidence in this case suggested deficient clamping pressures. Often, with continuous but erratic mechanical pummelling such as during the operation of the arc furnace, clamps can become loose and certainly release the

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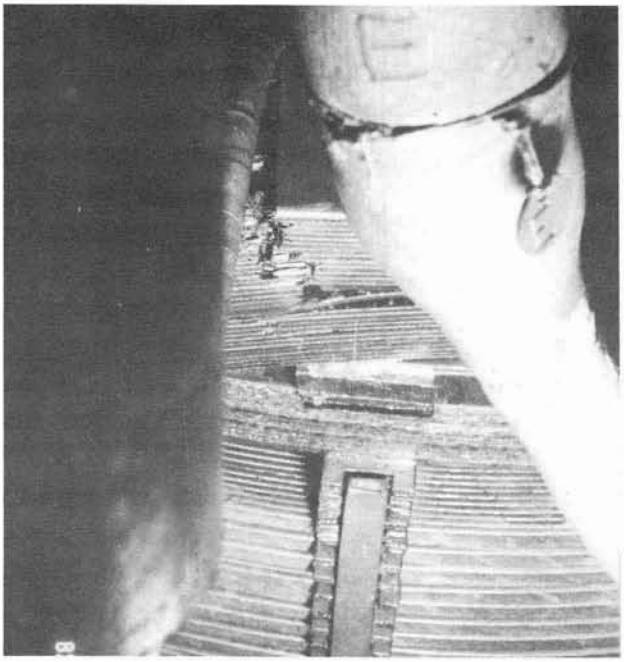
original design pressures. Also windings tend to shift and shrink with age and the combination of this and tough mechanical pounding can add to the changing and deteriorating clamping pressures. The solution - to ensure during any maintenance inspection of the transformer that the clamping pressures are adequate and adjusted if necessary.



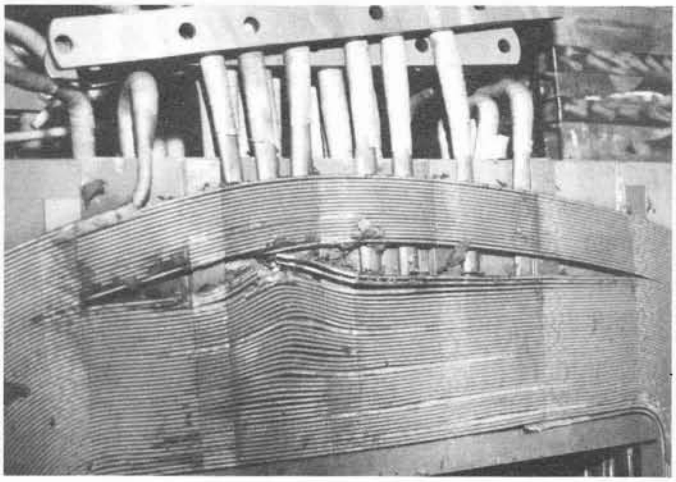
Broken high voltage coil blocking. Due to short circuit forces.

CASE III

A further problem was found in another transformer with loose extra-flexible primary leads. Again, insufficient consideration of the mechanical forces set up by the tough conditions experienced by arc furnace transformers was found to be the reason why the flexible lead insulation became chaffed and worn, resulting in a short circuit fault.

SOME SOLUTIONS

The solutions to preventing some arc furnace transformer failures will be found by considering what is happening to cause failure. It must be accepted that the loading of the furnace and the initial melt will set up abnormal conditions such as overvoltage, overcurrents and harmonic distortion and these should be provided for in the general design. However, there is no escaping the fact that the result will still be mechanical pounding, high but fluctuating currents and voltage distortions. The basics requirements then are to guard against this by ensuring that currents are kept within design limits and to minimum proportions by ensuring good contact surfaces and tight connections. If possible, monitor the heat generated by the high current bars with thermal imaging systems or heat sensitive devices now available. Include, or check, the relaying system which protects against extreme overcurrents and make sure such protection is adequate to give notice of early problems.



Shell type furnace transformer. High voltage winding, turn-to-turn failure.

Internal inspection of the transformer should be carried out at least once a year by independent experts in conjunction with the manufacturer. Certainly the first year of operation is important because that will be time when the greatest rate of changes such as relaxed clamping pressure may occur. In any internal

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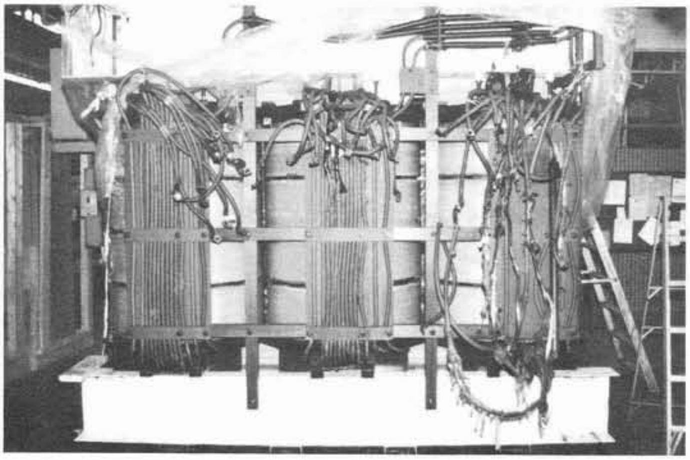


Failure of extra flexible, high voltage connections.

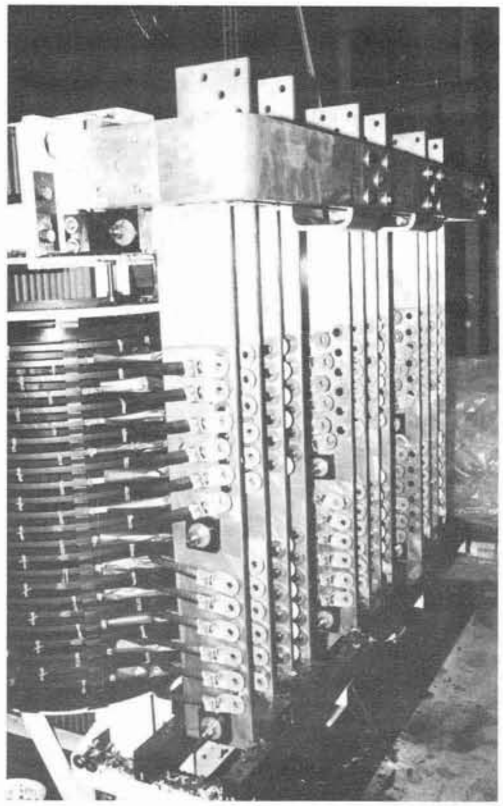
inspection, all clamping should be checked and if needed, retightened. All leads and connections should be secured and every effort made to make sure nothing is loose. The windings should be checked for insulation deterioration whenever possible.

In shell form units this is more difficult because of the particular construction, however, it may still be possible to make an inspection using boroscopes and similar devices.

As with all transformers, the best method to check on their health is to check the condition of the insulating oil. The severe conditions experienced by furnace transformers can lead to oil contamination much quicker than conventional units. Even evidence of severe gassing will be found. Therefore, regular and more frequent oil analysis checks are recommended - at least quarterly. All the usual ASTM oil tests should be done and also regular dissolved gas in oil analysis be taken. This technique is probably the best reliability tool we have at the moment. In addition to measuring the degree of polymerization of the paper insulation, this measures the chemical by products of the insulating paper degradation. In addition, it is suggested that infrared thermographic readings be taken of the tank and the connections to give a clear understanding of the extent of external heating. Internal temperature measurements on energized windings can also be done using a specialized technique.

Another problem which is sometimes overlooked is the location of the arc furnace transformer. The melting operation is not clean and if the transformer is located in an area where it can collect dirt and grime, especially on the bushings, then flashovers and insulator breakdowns can occur. Ideally, these transformers should be located in a clean, sometimes air-conditioned and pressurized vault.

Failures in arc furnace transformers are associated with high PD (property damage), high BI (business interruption) losses and large insurance deductibles. Professional independent inspection and diagnostics, taken on an ongoing basis, can go a long way towards reducing failures and eliminating unnecessary repair costs.



Internal connection failure on 18 MVA transformer.

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