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Staged Investment for Intelligent Automatic Transformers Winding Manufacturing Lines

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ABSTRACT.

Transformer manufacturers can be faced with difficult decisions when it comes to large-scale investment. Uncertainty can delay large-scale investments resulting in equipment with older technology and inefficient work procedures being left in production.

In this paper the authors expose a method where re-alignment of existing machines (through the integration of machine technologies such winding mandrels, wire flattening, cold welding, etc.…) can be done with incremental investment allowing companies to improve current processes while managing capital investment.

The application of the Staged Investment method proposed in this paper can be adapted to other peripheral transformer component manufacturing lines such as cores or tanks with excellent results.

Index Terms–Transformer winding, Staged Investment.

I. NOMENCLATURE - DEFINITIONS

Transformer coil: High Voltage and Low Voltage conductive parts of the transformer. Electrical energy is transferred between them.
Staged Investment: gradual use of funds to implement new technologies in a transformer manufacturing plant.

II. INTRODUCTION

The idea of intelligent and automatic machine operation are broad concepts in transformer coil production. They can mean different things to different people, depending on their current level of technology. As part of this presentation, MTM and H-J will present various modern concepts associated with intelligent and automatic machine operation that can be included in future machine considerations by transformer manufacturers, regardless of their size and the investment capacity. These concepts are applicable when considering new machines but can also be applied with respect to incremental improvements that can be made to existing equipment. These features can have a significant impact on the quality of the coil being produced while improving equipment productivity.

This paper will illustrate the positive economic impact and benefits of these concepts. Overall effects will vary depending on the user. We encourage the reader to make his own determination of real benefits based on the concepts presented. Many of these solutions have been implemented by transformer OEM's globally, with a high degree of success.

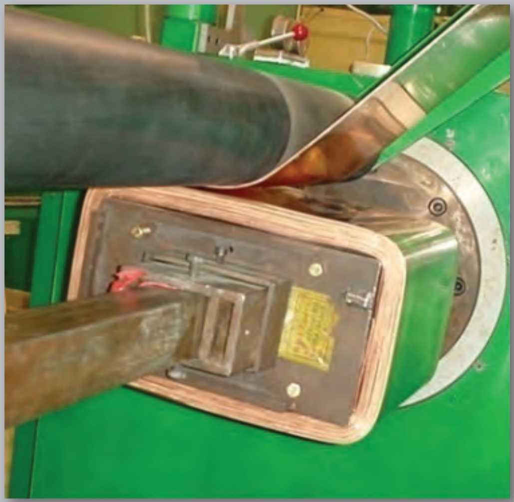
III. DEVELOPMENT OF THE CONCEPTS

Winding Machines can be divided into five classifications of design:

- Low Voltage Foil
- High Voltage Foil
- Distribution Wire
- Power Wire
- Combined LV Foil and Wire

Pictures below illustrate the typical standard product lines using some of these machine designs. Production capacity in terms of number of units and kVA size determines type and quantity of the winding machines.

Fig. 1. Typical Low Voltage Foil Winding Machine.



A. Combination of winding machines

Before making capital investments in separate HV and LV winding lines, combined machines (designed to wind foils and rectangular or round wires in the same machines) can be a good solution to save time and investment capital with production requirements are small. The addition of wire winding to a foil-winding machine are small when considering the price of a separate wire winding machine. Many "state of the art" features are present in this first step to the Intelligent Manufacturing Line:
The cost of adding HV wire feature to a LV winding machine is less than 40% of adding a new HV winding machine to the production line (cost dependent on the number / type of wires)

- Wires are guided onto the coils by PLC based automatic control systems, eliminating manual control of tension by the operator. This adds important quality value to the winding mainly to get the standard damage curve requirements per IEEE C57.109 for short circuit withstand capacity.
- Likewise, the coils are guided through the machine with automatic alignment and tension control. It improves the short circuit capacity by making easier the alignment of the HV and LV windings.
- Machine's PLC ensures the winding is done to program. No need to make further tests on turns ratio. This saves time and allows operator to concentrate in primary processes building quality into the process.
- In these machines, as in any last generation winding machines, the operator faces front to the coil being wound, with insulation, foils and wires feeding from the back of the machine. This way the winding operator controls easier quality facts like windings alignment and the need to refill any material as he is positioned in front of the pay offs.
- Production time is reduced through elimination of transport of the LV coil to the HV winding machine since the HV coil is applied to the LV winding in the same machine. Combined winding machines reduce production time up to 30%.
- Combined machines reduce the number of windings flowing in production (from 2 pieces to 1) which is part of the lean manufacturing concept to reduce work in process (WIP). Less time is used to handle the coils, stage the coils between operations, which reduces handling and the potential of damage.

Fig. 2. High Voltage Foil Winding Machine

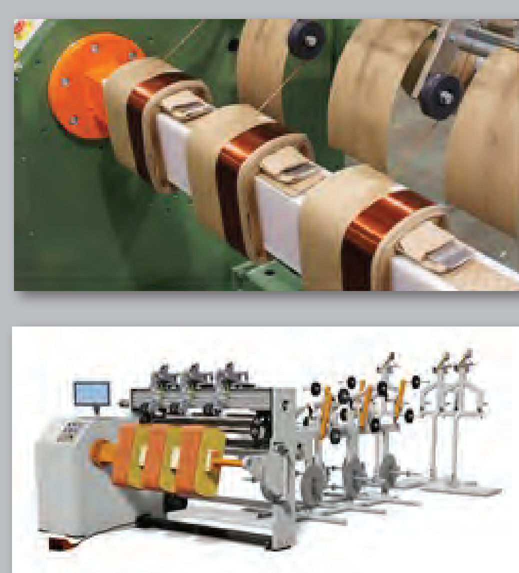


Fig. 3. Multiple Distribution Wire Machine

The features integrated into these machines can be standard or advanced. To begin with our incremental improvements method, a standard machine can be introduced using only single HV and LV coils winding systems and leaving multi-winding systems for further incremental steps. See B. below. However, combined machines can gain complexity including multi-coil winding systems. Figure 4 shows a typical layout of a large combined machine for large distribution or small power transformers using 2 parallel foils and up to 6 rectangular wires.

Fig. 4. Layout of a Large Foil & Wire Winding Machine

In last generation winding machines, operator faces front to the coil being wound. Insulation, foils and wires are fed from the back of the machine

B. Multi-coil production systems and setup of production cells in manufacturing

Once the volume of production increases, it gets convenient to move to our second incremental improvement: the multi-coil production concept and introduction of the production cells. This method takes into consideration the balancing of time to make LV vs. HV sections of the coil. This is a scaling up concept that builds on the idea of having a combination machine.

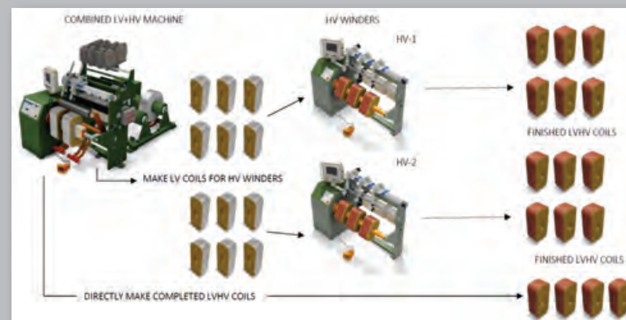


Fig. 5. Production Cell Concept
Combined Machine & HV Wire Machine System

Multiple coil machines are very useful mainly for HV coils due to the fact production time for HV coils may be 3 or 4 times the production time of LV coils (in some cases). Initially the machine may take a little longer set-up time, but once in operation, every turn of the machine will produce multiple coils. This results in production time per coil being reduced by about 1 divided by the number of coils mainly in small kVA rating transformers where the number of turns is high. Advantages are evident in the productivity of the process and the use of less machines for the same production volume. Typical reduction of production times when using triple HV winding machines is up to 60%, again a function of number of turns: the larger it is, the higher the productivity gains.

The production cell concept provides a method for balancing HV and LV coil production, which is a challenge due to the time differential in production of the two. This concept consists of combining HV winding machines with compact or combined HV/LV winding machines to achieve continuous production of both windings. While the combined machine produces many LV coils to feed the HV winders, it can also produce complete (HV plus LV) coils. Production of the LV coils can be scaled with production of the complete HV/LV coils in order to provide a balance in production of the coils, thus generating uninterrupted supply of both. Not having idle time easily reduces 20% of the total windings production time per day.

Data from each machine or group of machines can be collected and downloaded to a central location for analysis of the production flow.
Insight to the Production Process can be determined:

- Costing of each coil
- Trending in processes
- Bottle necks in the production process
- WIP management
- Variations in operator and machine performance

C. Automatic insulation cutting and tensioning systems

With older winding machines (without re-alignment) it can be difficult to control tension between HV layers of the coil. With LV coils "manual" or "non-uniform" tension is provided resulting in loose coils with poor short circuit strength. With newer machines insulation papers are tensioned and positioned near the coil so the operator can gain access during the winding. Uniform tension is applied. Machines can be equipped with an automatic cutting process of the insulation paper further speeding up the production process.

As the next incremental system improvement, insulation tensioning systems improve short circuit strength to the coil assembly for a relatively low investment. Figures 6 and 7 illustrate typical paper tensioning systems. Note that the papers are tensioned equally across coils on the machine, insuring equal tension within each coil. It must be reminded short circuits are main failure cause for distribution transformers.

D. Closed Loop Wire Tensioning Systems

With older winding machines (without re-alignment) it is common for round wire tension to be controlled with a mechanical brake (and possibly other mechanical systems). While this system provides tension to the wire, it is up to the machine operator to determine if the tension is correct. This is done by qualitative methods. With a closed loop tensioning system the designer will be able set the required tension range for a given conductor and the PLC system will maintain the tension through the coil winding. This is an advanced feature available on new winding machines. Keeping constant the wire tension at a certain value, adds uniformity to all manufactured windings assuring short circuit withstand ability to the transformer.

E. The gradient insulation system, also known as progressive insulation

The gradient insulation system employs the use of a continuous insulation strip to vary the thickness of the insulation across the winding layer according to the program.

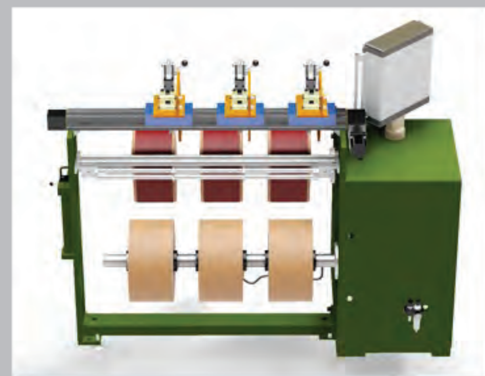


Fig. 7. Paper Tensioning System

This method allows the appropriate insulation thickness to be used where there is greatest difference in voltage potential, and less thickness where there is less potential. The net result is a reduction in coil diameter, with corresponding reduction in the amount (mass) of insulation used. Figures 8 and 9 show the Gradient Wrapping representation. Total winding material savings (conductor plus insulation) arounds 15%. Also, because the insulation layer is being wound at the same time as the wire section, the time to wind the HV section can decrease by as much as 30%.

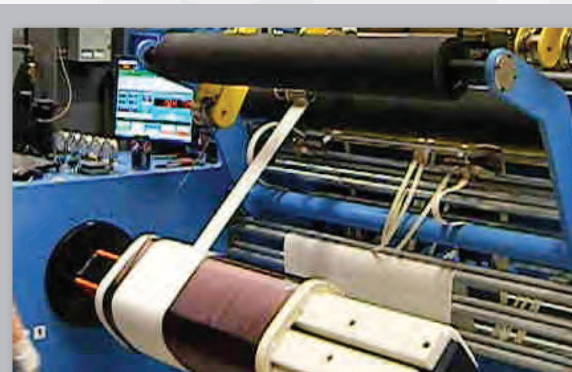


Fig. 8. Gradient Insulation System

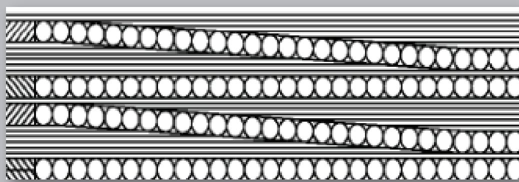


Fig. 9. Gradient Insulation System

This improvement is of great benefit to manufacturers using windings with gradual or reduced insulation mainly for grounded wye connection of power transformers.

F. Wire flattening – 1 or 2 wires:

- Round wire flattening is a well-known process providing important benefits in HV coil designs for distribution transformers such as:
- Reduction in air gap between turns, improving the space factor. This causes a reduction of the core window, reducing core losses.
- Reduces the electrical stress between layers by reducing the number of turns per layer. In some cases, reduction of the insulation thickness can be achieved.
- Substantially increases the surface of the conductor in contact with the insulation paper, thus increasing the short circuit strength by improving the adherence between layers.
- Reduction of the radial coil build by reducing the wire thickness by up to 20%. This means narrower core windows, less materials and losses. Total cost reduction between 5 to 10% can be reached by adding wire flatteners to the coil winding production line.

Wire flatteners can be added to existing machines. See Figure 11 below.

G. Cold Welding:

Cold welding of conductors, leads and terminals was developed to eliminate the need for heating of conductors either to join two conductor spools or to join conductors and terminals. In many cases this can require joints of different materials. Cold welding allows joins between copper to copper, copper to aluminum or aluminum to aluminum.

This incremental investment can reduce production time; however, its main impact is in the quality and long-term duration of the joins as e.g. many of the copper-aluminum joins are affected with the pass of the time by galvanic reactions in the contact areas creating hot spots that reduce transformer's life.

Fig. 11. Wire Flatteners added to an existing machine

The process is clean, quick, requires no cooling time, and can be added to existing machines. This process can also be provided by a stand-alone machine that is portable for transport between work centers. Cold Welding systems can be an integrated foil and lead cleaning system and vacuum for removal of debris. Design parameters for the cold-welding process can be computer controlled and integrated with the winding process.

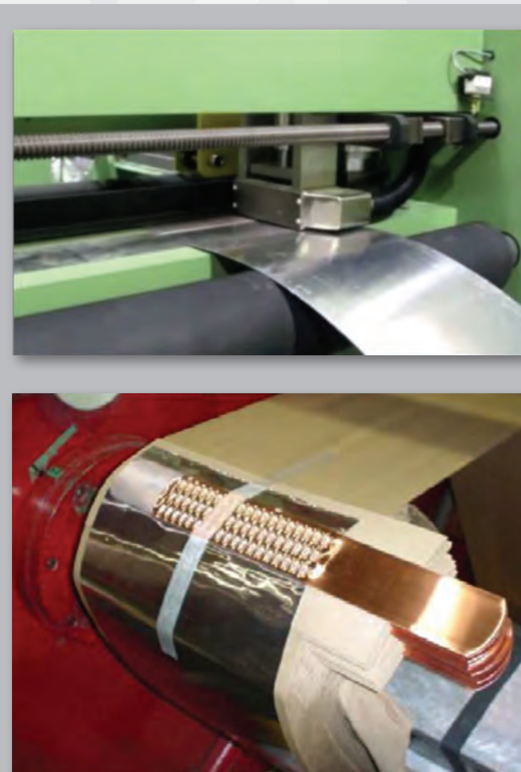


Fig. 12. Integrated Cold Welding System for Coil Terminals Distribution and Small Power Transformers

Fig. 12A. Portable Cold-Welding Unit for Coil Terminals Distribution and Small Power Transformers

H. *Winding Mandrels and Forms:*

Rectangular, oval and round expanding mandrels are necessary tools to produce compact coils for distribution and power transformers. Cost of these tools varies as a function of the transformer size. In general, the investment required increases exponentially with the kVA size of the transformers. Pneumatic or mechanically expanding versions are available. Quality mandrels keep windings alignment and tension helping to maintain transformer damage curve and winding dimensions within tolerance. It should be noted that rectangular mandrels can be designed with 2 or 4 way expansion (independent).

Fig. 13 Rectangular and Round Expanding Mandrels

IV. CONCLUSIONS

The methodology developed in this analysis illustrates how transformer manufacturers can employ the Staged Investment process to gradually implement Intelligent Automatic Transformer Coil Manufacturing Lines.

For those cases where manufacturers have low investment capacity, the proposed method of investment allows the manufacturer to start a plan with periodic investments that finally takes him to a completely automated production line gradually reducing costs and improving quality.

By using these methods and according to the experience of the authors, high tech production can be achieved by small or large manufacturers at their own pace of investment.

V. REFERENCES

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VI. BIOGRAPHIES

Orlando Giraldo was born in Pereira Colombia, on Feb 3, 1953. He graduated from the Technological University of Pereira. His employment experience included 13 years at the ABB Distribution Transformers Plant in Pereira and 13 years at the SIEMENS Distribution and Power Transformer Plant in Bogota Colombia. Fields of experience include design, production, tests and sales. He has also worked for many years in the Transformer Standards area in Colombia. He has been teacher of Electrical Machines at the Technological University of Pereira and at the National University of Colombia in Bogota. He is since 1999 with The H-J Family of Companies; currently Senior Consulting Engineer.

Gord Atamanchuk, P.Eng. has worked in various positions in machine development, manufacturing, and sales since graduating from the University of Manitoba with a Bachelor of Science in Mechanical Engineering in 2000. Gord's involvement in product design, testing, manufacturing, and service / support gives him unique expertise on the machine development process and the role technology plays in this environment. Gord is currently General Manager of Micro Tool & Machine Ltd. (MTM), an engineering firm specializing in custom machine design and automation to support various industries (including the transformer industry).