Precious metal heating control beyond energy efficiency

Glass Manufacturing Knowledge Series

Written by René Meuleman and Stanley F Rutkowski III
Edited by Amber Watkin

Eurotherm®

Executive Summary

Eurotherm in partnership with RoMan Manufacturing demonstrate the benefits of using Load Tap Changing (LTC) power control combined with low inductance equipment in precious metal heating control applications. The solution describes the benefits in terms of reduced energy usage and faster production rates with stronger more uniform end products.

Introduction

The idea for this project came from our glass manufacturing customers who needed to save energy in their manufacturing processes, so we took up the challenge to provide the most electrically efficient system for precious metal heating applications. Both Eurotherm and RoMan Manufacturing have many years' experience in the glass industry and have worked together for some time on modernisation projects to improve energy efficiency. New methods and equipment, utilising Eurotherm control strategy with automatic load tap changer, and low inductance equipment supplied by RoMan have been trialled in on-site testing and the results have shown significant energy savings. Customers could not only see the difference in energy consumption, but over time, were also reporting more uniform product quality. In order to see what was going on, the partnership decided to run some tests to visually demonstrate some of the effects of inductance and an augmented wave form on the cables, transformer and precious metal load.

Problems and solutions

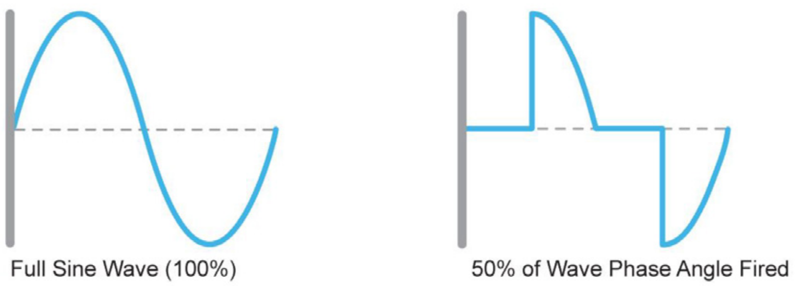
The problem with phase angle power control

Traditionally, power control to a precious metal heating load is provided by a silicon controlled rectifier (SCR) or thyristor using the phase angle firing method. This method offers smooth control to a high resolution of setpoint but causes distortion in the AC waveform within the cables and busbars due to the way the waveform is applied and the physical properties of the cables. In phase angle mode, the required power level is achieved by switching on the thyristor in a pulsed manner at a specific point during the AC sine wave. For example if 50% power is required, the thyristor is switched on by the controller for 50% of each sine wave, (between the peak of the wave and the zero crossing point).

Figure 1

Phase Angle Firing Waveforms

- *The power is controlled by 'chopping' the waveform*
- *Chopping causes harmonic distortion, increases the apparent power and lowers the power factor*



Reactance in the cables, busbars and power transformer, opposes the changing current and voltage, resulting in magnetic and electric fields. Combined with the inductive properties of the system, additional current and voltage is induced in the wiring that wastes energy in lost heat and also adds to the cost of electricity by negatively affecting the measurements made by the electricity supplier. The distortion in the sine wave, known as harmonics also causes vibration in the system that can damage the equipment and the product being made.

The problem with traditional system design

An ideal system design should have low inductance to help prevent harmonic distortion. A common solution is to fit shunt capacitor banks (SCBs) that compensate for the inductance in the system by adding capacitance. This relieves the circuit from the burden of carrying the extra reactive power. Only the circuit located before the SCB will benefit, so they need to be installed as close as possible to the transformer. Shunt capacitor banks represent extra investment because they themselves consume some power and require addition space and maintenance. It's not an ideal solution as shunt capacitors only compensate for the inductive phenomena, basically fighting against the damage already done to the waveform. A much better way to deal with the problem is to reduce the inductance in the first place.

One way to reduce inductance is to use specially designed low inductance busbars, cables, flexibles and shunts. Another way is to shorten the cable length. However, that would require the transformer to sit much closer to the load. This is not possible, with traditional air cooled transformers due to the fact that they need to be kept in a lower temperature environment, free from dust and debris that can reduce the cooling air flow. The only way to achieve such conditions is to isolate the air cooled transformer from the bushing area, which means you need longer and more costly copper busbars to supply power to the bushing. A better solution is to use water cooled transformers. These can be fitted closer to the bushing, reducing the length and cost of the busbars, but they can still be sensitive to the bushing heat, so are typically still fitted a short distance away.

How electricity is charged

The way electricity suppliers charge for energy varies by country and utility supplier. The most common charges are for real power (kW), apparent power (kVA) and power factor. The apparent power is the total power including the extra current and voltage caused by inductive reactance in the circuit. The power factor is the ratio of real power compared to the total apparent power.

The best the power factor can be is ‘1’ but due to harmonic distortion, figures of 0.6 or 0.7 are common in precious metal heating applications. Utility companies often set a power factor limit of around 0.9 and the industrial consumer then has to pay extra charges when the power factor is below that limit. For companies that fail to control their energy consumption well and run at a low power factor, the cost of energy is unnecessarily high. SCBs solve the problem to some extent but recent developments in power control are helping to solve the problem in a different way.

How is your electricity charged?

- *It varies by country and utility supplier, check your bill.*
- *Are you are charged by kWh, reactive power (KVA) or Power Factor?*
- *Once you know, you can start to implement more energy efficient solutions and begin avoiding penalties to reduce your energy bill.*

Improved system design from RoMan Manufacturing

The best possible solution is to fit the transformer directly adjacent to the bushing, and this is the challenge that the specialist expertise of RoMan overcame by designing an improved water cooled transformer to solve the problem. RoMan have been in business for 35 years and are a highly innovative transformer supplier focusing on customised solutions for specific applications, in this case fibreglass bushing transformers and related busbar and cabling designs. Through expert knowledge, they have developed relatively small water cooled transformers, sealed in epoxy resin that prevents contamination from dust and debris, and protects it from heat. This means that it can be placed much closer to the bushing than regular water cooled transformers, in fact directly beneath it. The small transformer size with improved insensitivity to the heat of the bushing has also made it possible to design much shorter low-inductance high-current busbars and associated flexibles, cables and shunts.

Improving the power factor

To achieve an acceptable power factor close to 1, the thyristor controller needs to supply as clean a waveform as possible with the least amount of harmonics, in this case a power demand setpoint somewhere above 80% of range. However, in an average precious metal heating application you need to have at least another 10% of control either way, in case the load temperature needs to be adjusted quickly after an incident. In a typical plant, the engineer needs to choose a transformer voltage tap that supplies the closest power to these settings, resulting in many systems being run at approximately 70% to 80%. The result is a power factor that is not as good as it could be, often at a value of 0.6 to 0.7 which will incur extra electricity charges.

Unfortunately tap changing is not always an easy job to perform, especially "on-the-fly" and requires a dedicated service engineer to manually switch the taps by hand each time the bushing power demand changes during temperature ramps. It also involves switching off the bushing to get into the internal parts of the transformer, causing unnecessary interruptions in production.

In a majority of installations this kind of system needs ongoing attention and mechanical maintenance in order to maintain an acceptable power factor, and in our experience most of the bushing control systems we investigate are not running in ideal conditions, in fact we find many applications running under severe conditions. Apart from the energy wastage issue, at its worst, harmonic distortion can trip relays, circuit breakers and interfere with communication and other equipment such as computers.

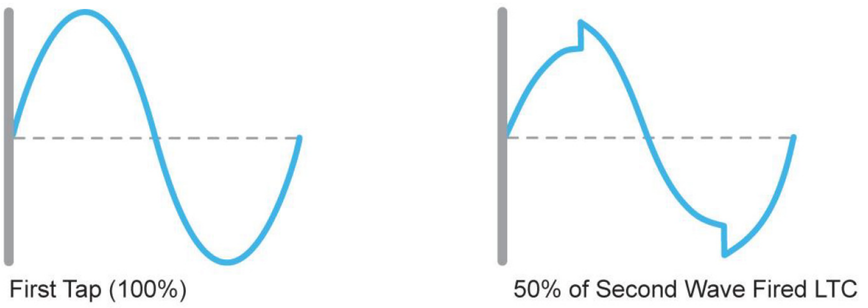
Eurotherm improved power control solution

The way to improve power factor by always running the system at a power demand setpoint above 80%, is to invest in an SCR controller that can automatically switch transformer taps dynamically without manual intervention. In the case of Eurotherm, we recommend the EPower controller range with automatic Load Tap Changer (LTC) functionality. EPower can be connected to multiple taps of the transformer and configured to automatically switch between them dependant on the power demand of the bushing.

Figure 2

Load Tap Changer Wave forms

- *The first tap supplies a full waveform (100%)*
- *The second tap switches in to supply extra power when there is more demand*
- *The LTC waveform is not 'chopped' so there is much less harmonic distortion, resulting in a higher power factor and less wasted energy*



Supplying the power in this way provides a more complete sine wave rather than the 'chopped' wave seen using phase angle on its own. This significantly reduces the harmonic distortion that affects the power factor. The extra power demand is supplied when the second tap is switched on in phase angle mode, using special algorithms unique to Eurotherm that continuously calculate and automatically select the best tap arrangement to fit the situation. EPower is capable of controlling multiple thyristor stacks attached to multiple taps of a transformer dynamically, instead of having to carry out laborious manual tap changes, allowing seamless control from 0-100% power demand while maintaining the best possible power factor at all times.

Proving the Theory

The aim of the initial project was to lower the inductance in the system in order to reduce the harmonics. The following controlled tests were carried out in a laboratory environment to validate the theory behind the Eurotherm RoMan solution and show the effect of the improvements.

Test Process

Equipment

A Eurotherm EPower controller was used to demonstrate the effects of both phase angle firing (traditional chopped waveform) and automatic load tap changing (LTC), on a simulated precious metal heating element created by RoMan from stainless steel for test purposes.

To show the difference between a high inductance and low inductance circuit, RoMan set up two secondary circuits (transformer to load), one defined as highly inductive 'large loop', the other defined as low inductance 'small loop'

Figure 3

Large Loop (high inductance)

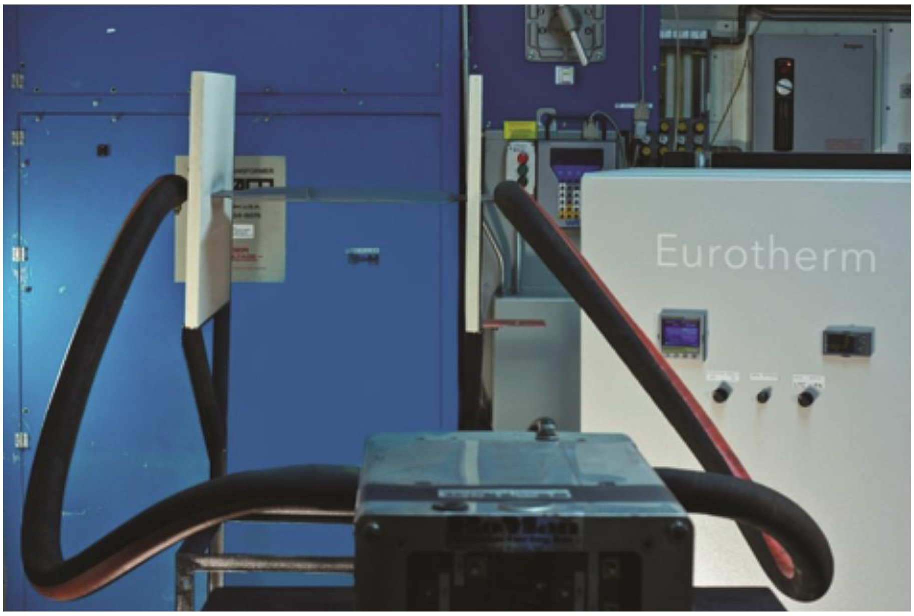
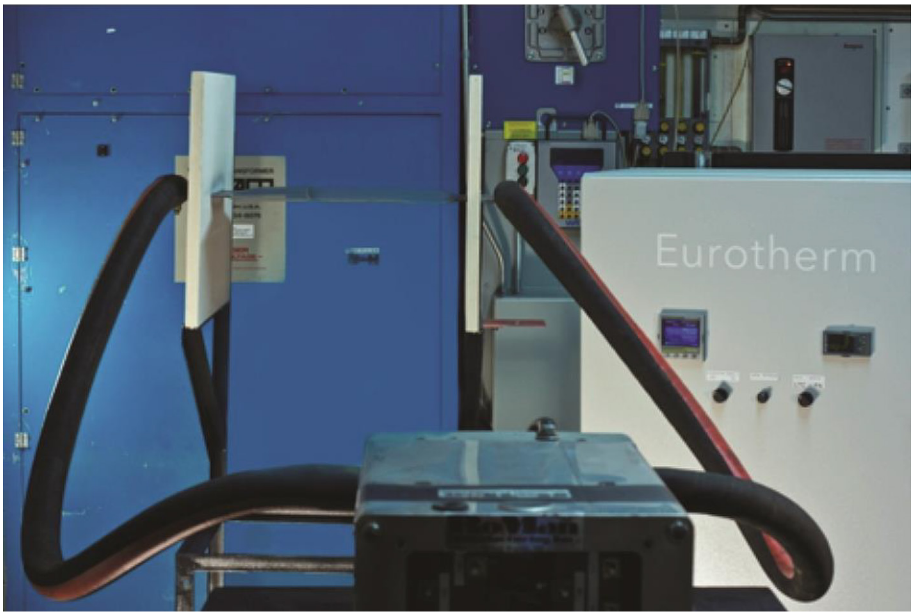


Figure 4

Small Loop (low inductance)

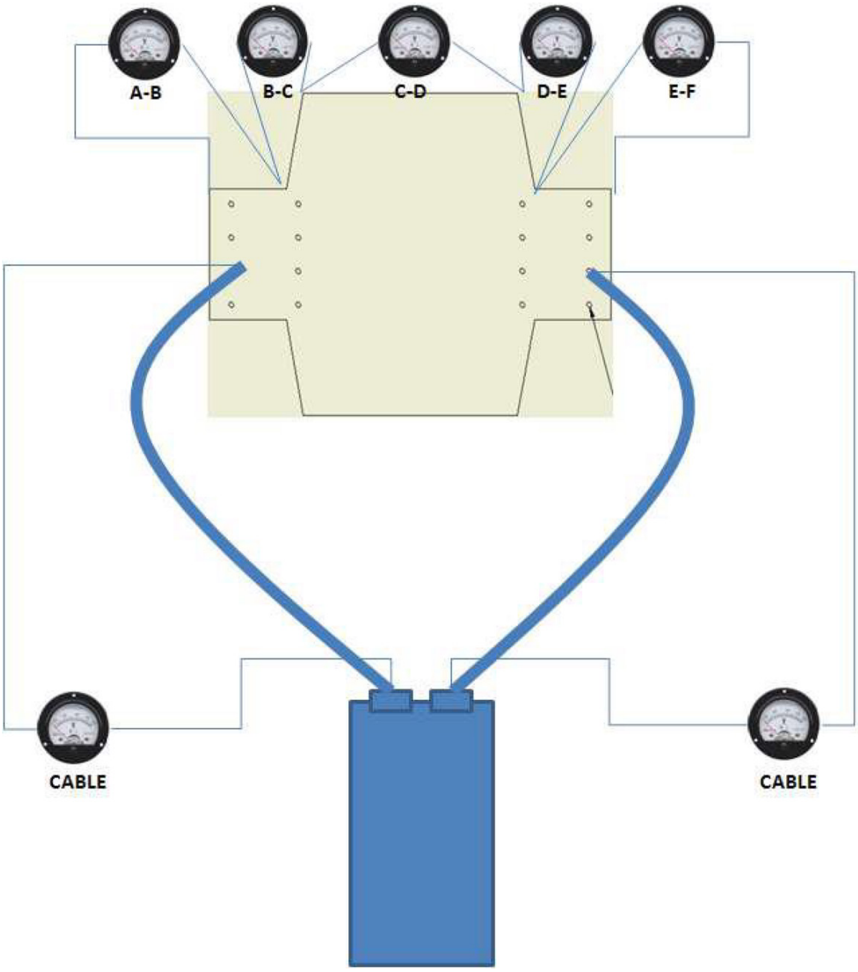


Controlled testing

Meters were attached to different points across the heater load in order to measure the power, current, voltage and waveforms (see Figure 5), and an FLIR thermal imaging camera was used to record the heat patterns.

Figure 5

Meter measurement points on precious metal load



Iron flakes were applied on top of the load to visually identify the magnetic patterns created during each test (see Figure 6).

Figure 6

Iron flake test setup

Results

Power, voltage and current comparison

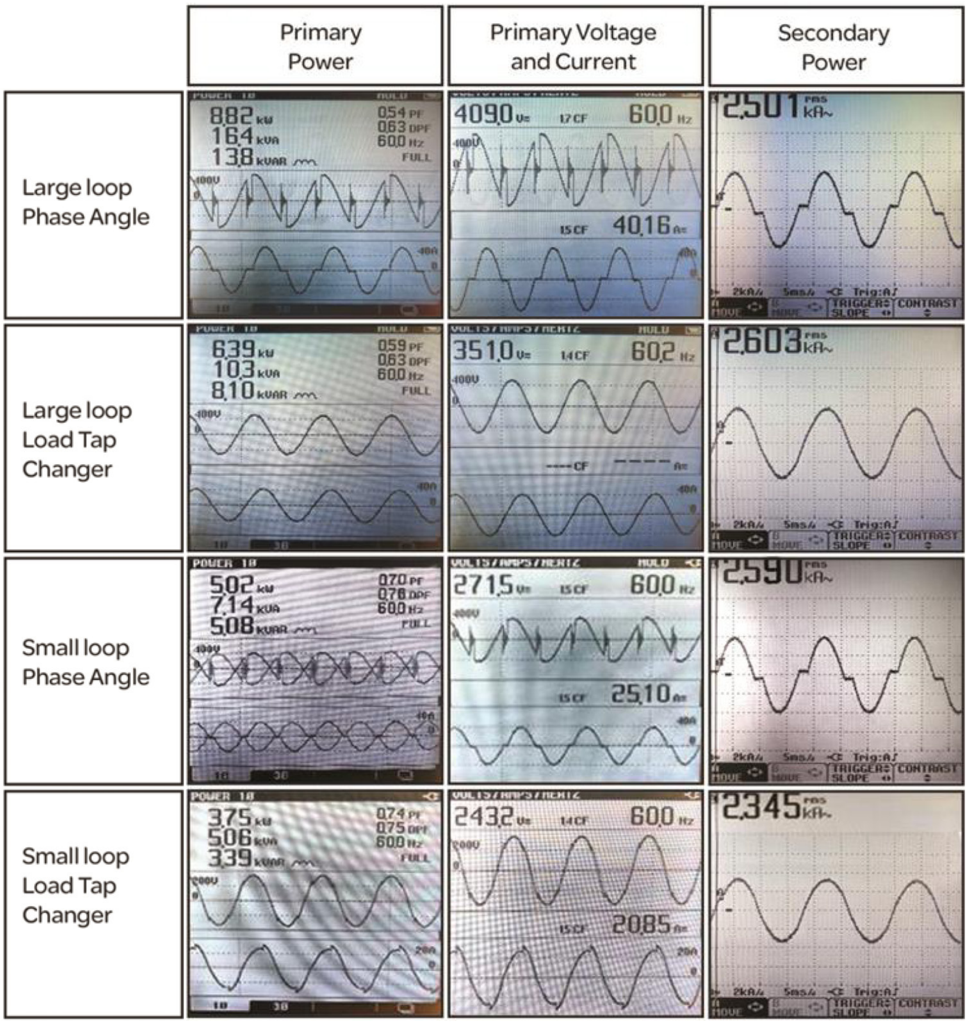
From the waveform results in **Figure 7** you can see the following:

The load tap changer function on the EPower provided a much cleaner AC voltage signal to the primary of the transformer than the standard phase angle fired signal, resulting in a clean secondary waveform and in the case of the low inductance circuit, reduced current.

As you look down the Primary Power column, the Real Power (kW), Total Power (kVA) and Reactive Power (kVAR) values decreased as the Power Factor increased.

Figure 7

Power, voltage and current waveform results



Heat pattern and iron flake test comparisons

The heat pattern in Figure 8, clearly demonstrated the effect of harmonics on the precious metal load. More current was present in the large loop circuits which can be seen as non-uniform additional heat. This is due to skin effect which reduces the amount of current passing through the centre of the conductor and concentrates it to the outside (or skin). The ideal situation is that the current runs equally through the load, not affected by any inductance or harmonics, which is demonstrated on the small loop (low inductance) circuit results.

The small loop, low inductance circuit with LTC heat pattern showed the best result, demonstrating less heat in the load (less current) and more uniform heating across the load.

The effect was also confirmed by the iron flake testing method in Figure 9, where the current had induced magnetic fields at the edges of the load due to harmonics in the phase angle circuit. The uniform flakes in the low inductance circuit using load tap changer method confirm that the harmonics were greatly reduced.

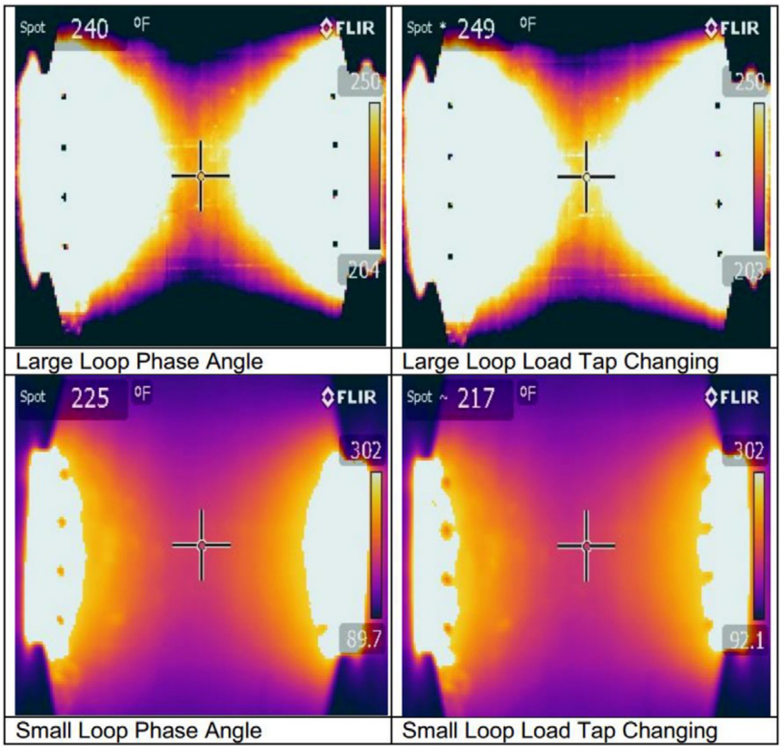


Figure 8

Heat pattern comparisons

The low inductance circuit with load tap changer demonstrated the most uniform heating method with the least waste of energy.

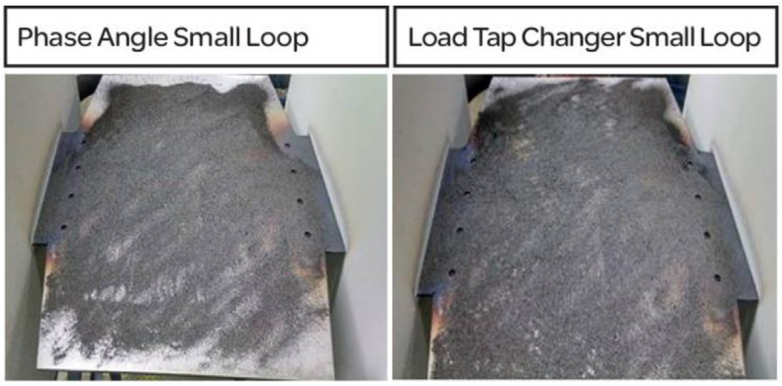


Figure 8

Iron flake test comparisons

The low inductance circuit with load tap changer demonstrated that reduced harmonics allow a more uniform current flow through the load.

Vibration tests

The data visibly demonstrated the negative effect of phase angle firing in a higher inductance circuit by causing the most mechanical vibration in the load. The advantages of reducing harmonics with a lower inductance circuit include less variation in the made product due to reduced mechanical stress applied to the material during manufacturing, and increased life of the precious metal load.

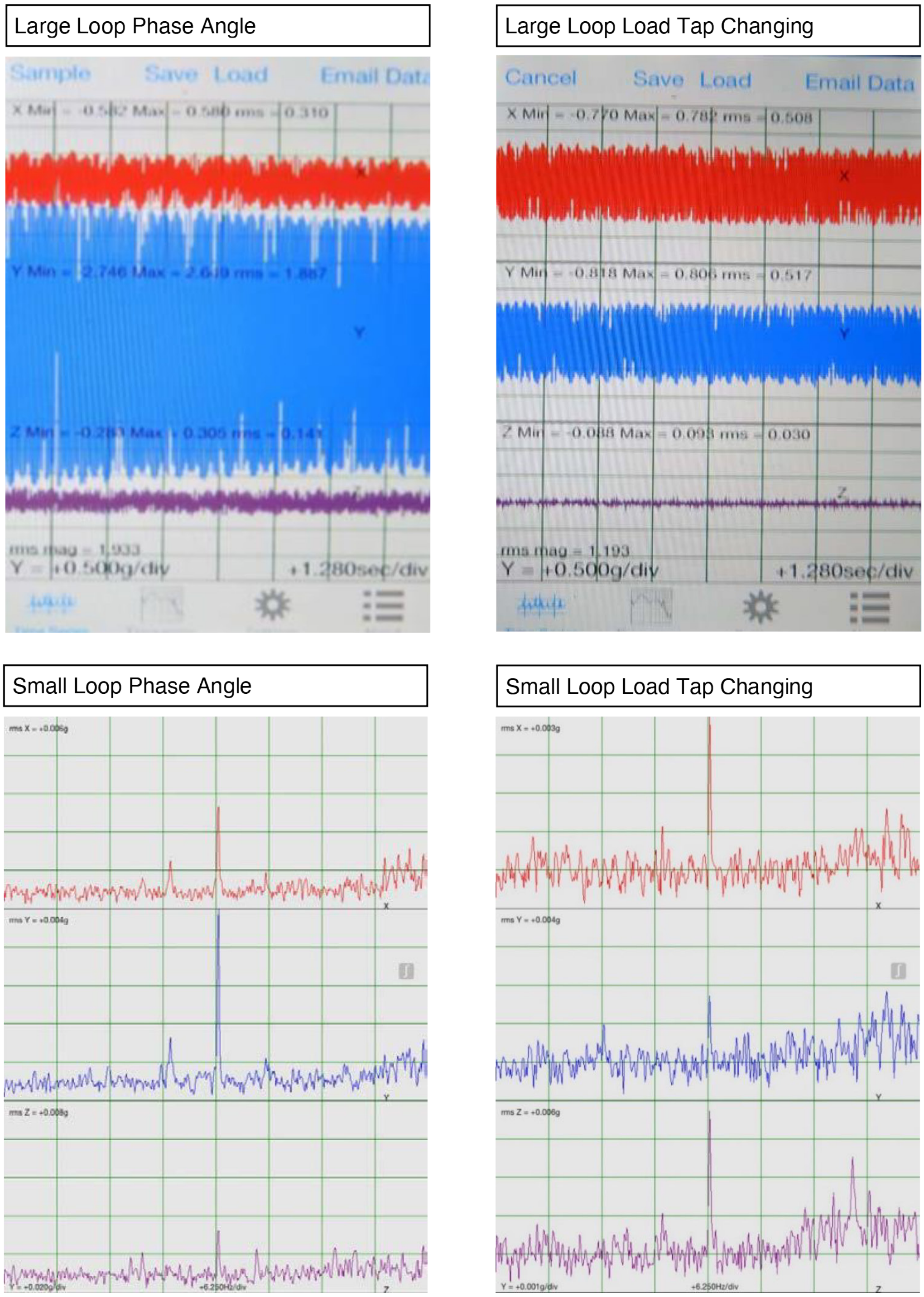


Figure 10

Vibration test comparisons

Conclusion

The LTC strategy within the Eurotherm EPower controller, combined with expertly designed power transformers and busbars from RoMan, are proven to save energy but also show additional improvements. Benefits include, reduced system maintenance through extended life of equipment and increased throughput by enabling glass manufacturers to make stronger better quality products with less variation.

- Less apparent power is used in the low inductance circuit with automatic load tap changing applied, and the power factor is increased, meaning less total power is used. This can result in electricity savings as these parameters are the measurements utility companies often base their charges on.
- The lower inductance small loop system with load tap changer demonstrated a more uniform heating pattern in the load, confirmed by the thermal camera and iron flake tests. Possible outcomes include, increased production rate through less variation in the made product.
- There is visibly less vibration in the small loop system which means less variation in the made product and increased life of the precious metal load.
- The increase in power factor could allow for the removal of capacitor banks in the system. Less voltage requirements on the load side of the system means less primary current needs to used in the system for the same production rate.The benefits include energy savings due to less peak demand on the power system and possibly lowering the ratings of upstream devices such as SCRs, breakers, cables and bus bars.

Eurotherm offers free ROI energy surveys to assess the savings that can be made by installing our improved power control system.

Get the most from your process

Contact us at www.eurotherm.com/industries/glass/contact

To find out more visit www.eurotherm.com/glass/

WATLOW.

About the authors

René Meuleman has over 30 years' experience working as an engineer within the glass industry involved in the design and development of container glass quality electronic equipment, implementation of the first generation Programmable Logic Controller (PLC) and Distributed Control Systems (DCS) and electronic timing systems for IS-machines, model based predictive control projects and object oriented engineering method developments. He became responsible for process control inside the BSN group and later was responsible for the European plant process control and forming electronics inside the Owens-Illinois group. At Eurotherm, René took the role of Process and Power Control Solutions, Energy Management and Model Predictive Control (MPC) for end-users, OEMs and solution providers. His motto is: "If you wait, all that happens is that you get older".

Stanley F. Rutkowski III, Senior Applications Engineer at RoMan Manufacturing Inc.

Amber Watkin, editor, has over 25 years' experience in the Eurotherm portfolio, covering Glass, Heat Treatment, Semiconductor, Life Science, and Food and Beverage industries. She has been responsible for promoting Eurotherm energy saving, efficiency enhancing solutions and services, designed for energy intensive, high performance, specialized and regulated thermal processing applications.

Eurotherm

Faraday Close, Worthing,
West Sussex, BN13 3PL
United Kingdom

Phone: + 44 (0)1903 268500

www.eurotherm.com

Contact your local sales representative

INVESTORS IN PEOPLE

Document number HA033845 Issue 2

WATLOW® Powered by Possibility

Published September 2023