ACHIEVING THE OPTIMUM MELTING POWER IN THE EAF AND THE USE OF GRAFTECH SPECIAL EAF MONITORING SYSTEM [1]

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Abstract
In the last few of years there has been a boom in the steel market that has pushed operations to their design capacity limits and then beyond. Many melt shops equipped with supplementary reactors as part of their equipment are now bypassing them at flat bath as a way to increase melting capacity. Many other shops are reviewing their existing transformer and redefining the operating points, as a way to take advantage of this great opportunity the steel market offers. GrafTech Technical Service personnel have been following many of these installations in North America; coincidental with this event we have developed new EAF monitoring equipment that has been instrumental in quickly determining the optimum operating settings for the EAF from the stand point of the electrical parameters. This paper will cover some of the latest examples involving cooperative and coordinated efforts to solve specific critical situations related to the EAF operation and the optimum use of melting power in a North American melt shop.
Key words: Maximum power; Arc stability; Regulation; Megawatts.

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INTRODUCTION

In the ups and downs of the steel industry and the market they serve there is always a balance between running the furnaces (EAF) at the optimum cost of production ($/Ton) and running the furnaces at the maximum production rates (Ton/hour). Many papers have been written stating that sometimes the fastest way does not necessarily coincide with the best operating cost.

Before 2004, the worlds' steel industry went thru a major slump, as we all remember. Several steelmakers in the United States went bankrupt at that time, a situation that, in fact, led to the consolidation of many steel shops, not only in the USA but around the world. Back in those days, the main concern of the steel producers was to stay in business, or in other words – to survive! Several efforts were made searching for ways to lower the production cost, without necessarily increasing the production unit throughput.

From 2004 this dramatic situation completely changed. Now there was not enough steel being produced; there was a market for every single ton of steel produced so the new goal was to increase the rate of production as soon as economically possible. This situation applied to both integrated steel making (BF/BOF) and the electric arc furnace steel making.

Around the same timeframe, our customer technical service group started experiencing the gradual loss of our 10 to 15 year old monitoring equipment. This was mainly due to wear and tear related to constant travel to service our customers combined with equipment obsolescence.

As in the case of the many previous versions of our Portable Arc Furnace Analyzer (PAFA) we searched the market for feasible substitutes. After several months of research and interviews with power monitoring equipment suppliers, we came to the conclusion that we needed to develop the whole concept ourselves. Many meters available today as off-the-shelf products only met segments or portions of the design needs specified for our next generation PAFA.

In this work we are going to share some of the experiences that a few steel makers in the USA went through in order to increase their EAF melting capacity. We will also describe some of the features of our new EAF monitoring equipment and the way this tool helped us better support our customers in achieving their goals. In every case, there was a process of melting power optimization by means of regulation system improvement / replacement or melting power program re-definition, with little or no capital expenditure involved at all.

EFFICIENCY OF THE USE OF TIME AND MELTING POWER

From many productivity studies performed over time, Raley et al.[1] developed the Productivity Equation that describes very well the interactions between the use of time and average power, for a given set of EAF size and transformer capacity.

$$P = \frac{TPY}{N \bullet Wpy \bullet Trn \bullet Ht \bullet Y \bullet FA} = TPH\,(chge)$$

Where:

P	=	charge tons per hour
TPY	=	liquid tons per year
N	=	number of furnaces
Wpy	=	operating weeks per year
Trn	=	operating turns per week
Ht	=	hours per turn
Y	=	charge to liquid yield, and…
FA	=	furnace availability

Using this equation we can determine the design capacity of a transformer, given the yearly production needs and a few estimations of power–on to power–off ratios, as well as projected specific energy consumption.

Perhaps the best use for this equation is to show that the first choice to optimize any EAF operation would be to improve the use of available operating time. As an example, for every 5 minutes of power–off per heat (delays or logistics) estimated in the project we should consider an additional 6 to 7 MW average power to maintain a yearly production of one million TPY in a single 150 Ton EAF installation.

Even though there may be several operations in the world that still have relatively low ratios of time utilization (%TU), many progressive operations in the United States as well as in other countries are reporting consistently excellent ratios of TU around 75 to 83%, or better on some occasions. In cases like these, the only way to increase EAF output would be through the increase of melting power.

The most common route for this purpose is the use of supplementary chemical energy. With this, some of the energy needed to process the metal is provided by the oxidation of carbon and other elements in the charge. The use of liquid iron or even solid pig iron will also help increase the output of a given EAF installation.

Once these avenues have been exhausted, then people usually return to review the efficiency of the transformer capacity. Next we present an example in which the actual rate of production has been improved by means of increasing the average melting power by way of improving the use of existing equipment (same transformer), implementation of different melting profiles, improvement of regulation performance, etcetera.

ONE MILLION TONNE PER YEAR - 110 TONNE EAF, POWERED BY A 120 MVA TRANSFORMER

This melt shop, as many around the United States, started operations right at the end of the previous steel market boom. By the time it was ready to roll the steel market hit a 3 to 4 year depression. Due to these conditions, the melt shop would run at night or off peak hours most of the time, as a means to keep the melting cost down. Later, when the market changed, all of a sudden there was a need for more production and the ‘little details” of the installation started to appear. The melt shop characteristics are listed in the table below.

Table 1. Design data for 110 tonne / 1 Million TPY EAF

Description	Units
EAF type	AC – three phase, high reactance
Shell Diameter	24 feet
Transformer capacity	120 MVA
Maximum secondary voltage	1400 V
Maximum secondary current (120 MVA)	58 kA
Oxygen injection system	Coherent O_2 injectors + burners

Worthy of mention is the fact that this operation was already one of our benchmarking melt shops with good production parameters like Time Utilization efficiency equal or better than 70%, more than 100 TPH, 30 heats+ per day, average power per heat above 80 MW, etc. The design capacity of this operation was approximately 1 million TPY. The following table displays some of the typical performance data while the furnace was running using the original equipment and settings, prior to the changes in power program and regulation revamping and adjustments.

Table 2. EAF Performance data before changes

	EAF Operating data	**Benchmarking**	
		Average	Range
Tons per Hour	130	98	40 – 150
Tap to Tap (Min)	46	62	41 – 90
Power On (Min)	33		
Power Off (Min)	13	18	8 – 32
Time Utilization (%)	72%	74%	58 - 92
Average Power (MW)	86		
kWh/t (Tap)	420	380	310 – 470
Tot. Oxygen (Nm^3/T)	31		
Tot. kWh/t	600	525	440 – 610

The optimization process at this location took several steps, starting with the substitution of the EAF regulator, along with changing the melting practice and re-designing the melting program.

Arc Stability and Melting Power – one of the first goals we defined at this melt shop was to devise a power program and regulation profile that would promote good arc stability throughout the heat. The use of very long arc settings early in the heat did not help much getting the arcs stable at this point during the melt. Using the transformer's nameplate data we started defining the operating set-points for the different stages of the operation, increasing the arc voltage (i.e. arc length) as the heat progresses in time and temperature.

As displayed in the heat profiles before changes (Figure 1) it was quite common to observe large kA swings early in the heat. This was, in part, due to the fact that the regulator settings did not match the needs for melting the type of scrap mix this furnace processes, i.e. medium to heavy scrap most of the time but sometimes made radical changes to large percentages of light scrap, depending on the melt shop's needs. At the beginning of the heat we used to observe frequent kA swings approximately 30 to 40 kA in magnitude. As expressed in other studies, the power input is reduced significantly when such large changes of current occur.

Once the rough melting stage of the heat subsided, the electrodes stabilized and large swings of kA were no longer detected (with some late cave-ins from time to time). In other words, the potential for improvement was largely dependant on finding the regulation adjustments that would improve the arc stability at the beginning of the heat, as well as in the melting tap selection or power program.

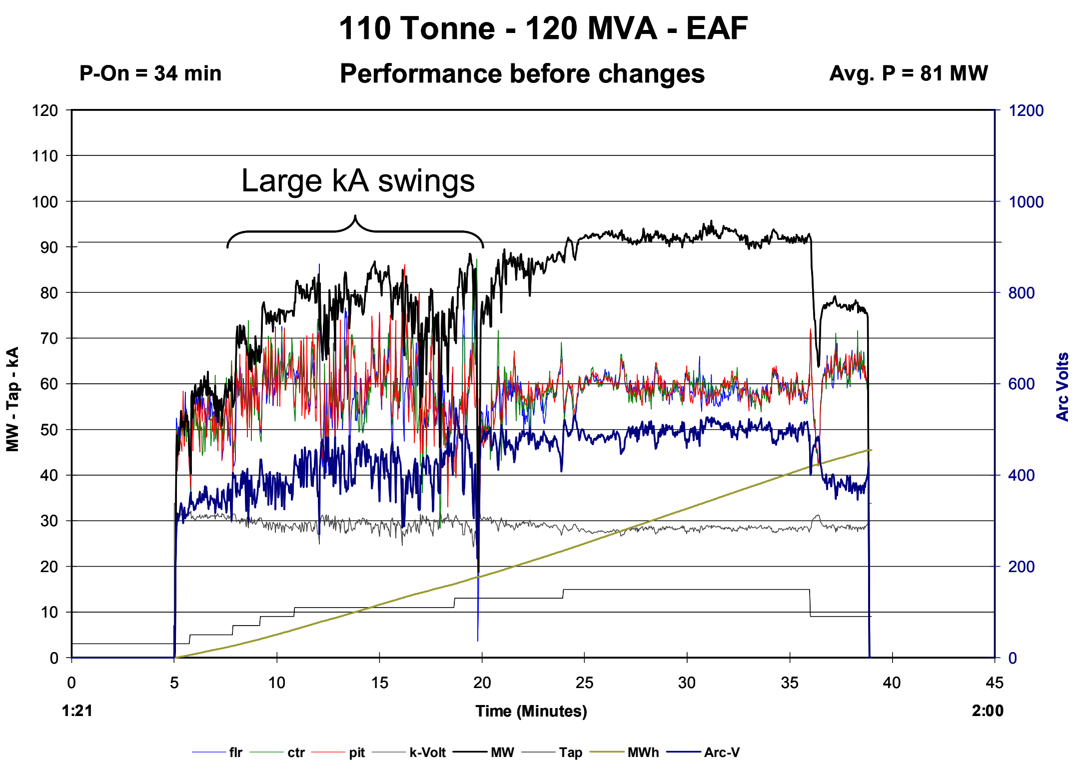

Figure – 1 Typical heat profile before changes

The Power Program – Once the need for improved melting characteristics was identified, we began evaluating the existing power program before we suggested any changes. The first thing we learnt was the fact that in almost all cases the power program to process the heat was not being followed or observed by the operators. We used this program as baseline but soon we realized that the reason the operators did not follow it was because it was very mild in terms of the maximum voltage tap used during melting, as well as the kA set points in general.

We decided to follow instead the melting practices and the experience of the EAF operators whose very positive attitude and aggressiveness regarding potential improvements were instrumental in finding the best melting practice that later translated into the new power program for this fine melt shop.

The main difference between these changes was the fact that practically there was no consistency in the way the furnace was operated. It was frequently observed that the initial bore-in stage would be prolonged for several minutes, depending on the “feeling” of the EAF operator; in other instances we observed very good melting profiles. As shown in the melting profile displayed in Figure 1, it could take up to 20 minutes before the highest melting tap could be reached. Converse to this, the new power program stayed on the low taps the minimum time possible, as Figure 2 shows the highest melting tap was already being used 5 to 6 minutes after power-on

The immediate results were obvious to everybody, a power-on time reduction was achieved at the end of the first session of adjustments. One thing we have also learned with time is that the hard thing is not to get a measurable improvement in the operation, the hard thing is to maintain it.

EAF Regulator change- The regulator supplied originally by the manufacturer became obsolete and for reasons outside the scope of this study was substituted at the time this work was being done. In today’s world, there is a vast need for fast speed response and accuracy in the way the electrodes react to the scrap movement during the melting process.

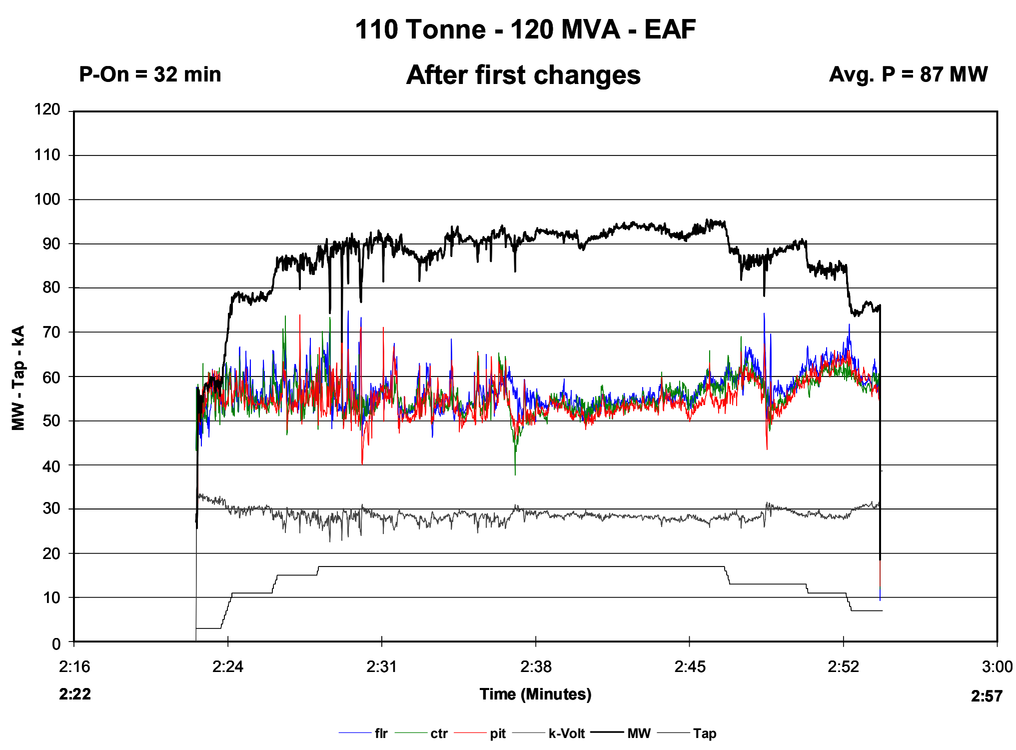

Figure – 2 Heat profile after regulation change

Many regulators in the market today provide a feature pioneered, amongst others, by Brown Boveri Corporation (later ABB); “the multiple gains settings”. With this feature, the regulator response is optimized to match the various stages in the heat. After deciding to go ahead and substitute the EAF regulator, the new system provided with this multiple gain selection and many other features helped us customize the EAF response to the melting practice at this location.

After upgrading the regulator, a positive change was reported immediately. Better control of the operating set points was obviously achieved.
The following table shows the "after" EAF parameters for the change in the regulator.

Table 3 Effect of regulator changes

	After regulator change
Tons per Hour	140
Tap to Tap (Min)	45.8
Power On (Min)	32.5
Power Off (Min)	13.3
Time Utilization (%)	71%
Average Power(MW)	86
kWh/t (Tap)	437
Tot. Oxygen (Nm^3/T)	31
Tot. kWh/t	605

EAF regulator settings and power program optimization - After upgrading the regulation control there was still the need for finding the appropriate settings to obtain the optimum use of power throughout the heat. Originally the regulator was set to respond conservatively to scrap motions and this gave fairly good results. Later, a more aggressive profile was tested with excellent results in terms of improved average power per heat and arc stability.

Table 4 EAF Performance after all changes

	After all changes	Benchmarking	
		Average	Range
Tons per Hour	163	98	40 – 150
Tap to Tap (Min)	40	62	41 – 90
Power On (Min)	29.5		
Power Off (Min)	10.5	18	8 – 32
Time Utilization (%)	74%	74%	58 – 92
Average Power (MW)	91		
kWh/t (Tap)	417	380	310 – 470
Tot. Oxygen (Nm^3/T)	30		
Tot. kWh/t	580	525	440 – 610

The combined result of all these changes was: Power-On time reduction, electrode breakage reduction and with these, the monthly production increased approximately 7 to 10%. Another positive side effect of this optimization process was the team building process that took effect while working with the EAF operators and maintenance and process personnel.

Table 5 EAF Performance after changes and comparison of results

Performance comparison			
	Before	**After**	**Diff**
Tons per Hour	130	163	25%
Tap to Tap (Min)	46	40	-13%
Power On (Min)	33	29.5	-11%
Power Off (Min)	13	10.5	-19%
Time Utilization (%)	72%	74%	2%
Average Power (MW)	86	91	6%
kWh/t (Tap)	420	417	-1%
Tot. Oxygen (Nm^3/t)	31	30	-3%
Tot. kWh/t	600	580	-3%

THE GRAFTECH PORTABLE ARC FURNACE MONITOR

Back in the early eighties we started using portable computerized means to record and analyze EAF electrical performance. At that time the equipment was pretty much a strip data recording system with no online analytical capacity at all. Later, in the early nineties, our technical people devised the second PAFA (Portable Arc Furnace Analyzer) with capabilities to perform some real-time data trending and quasi real-time current intensity balance analysis and histograms, to evaluate electrode regulation performance, amongst a few other studies.

Over the last few years an effort to develop a new monitoring system was carried out with the aim to cover many features needed in the electrical steelmaking field of today. After considering many choices of "off-the-shelf" monitoring equipment that covered some of the defined needs for our future PAFA but not all of them, a decision was made to go ahead and "develop the meter from scratch". The decision was also made to use as much readily available proven hardware technology as possible, thus minimizing equipment customization. The challenge was to find an adequate hardware platform and develop necessary software. The completed system would not only perform the traditional analysis functions, but also be able to accommodate the known requirements as well as yet to be determined future requirements.

Some of the specific needs the new system must address are:

1. Portability
2. Monitor 3 phase electrical systems
3. Monitor 50 / 60 Hz electrical line frequencies.
4. Multiple simultaneous signal sampling
5. Monitor primary and secondary electrical circuits simultaneously
6. Sampling speed for electrical harmonic and wave form analysis.
7. Monitor auxiliary signals, i.e. transformer tap position, oxygen flow.

8. Real-time numeric and graphical display of monitored and calculated parameters.
9. *"Fault Recorder"* capability with pre and post event triggers
10. Electrical and production analyses from microseconds to months.
11. Data archive of several months

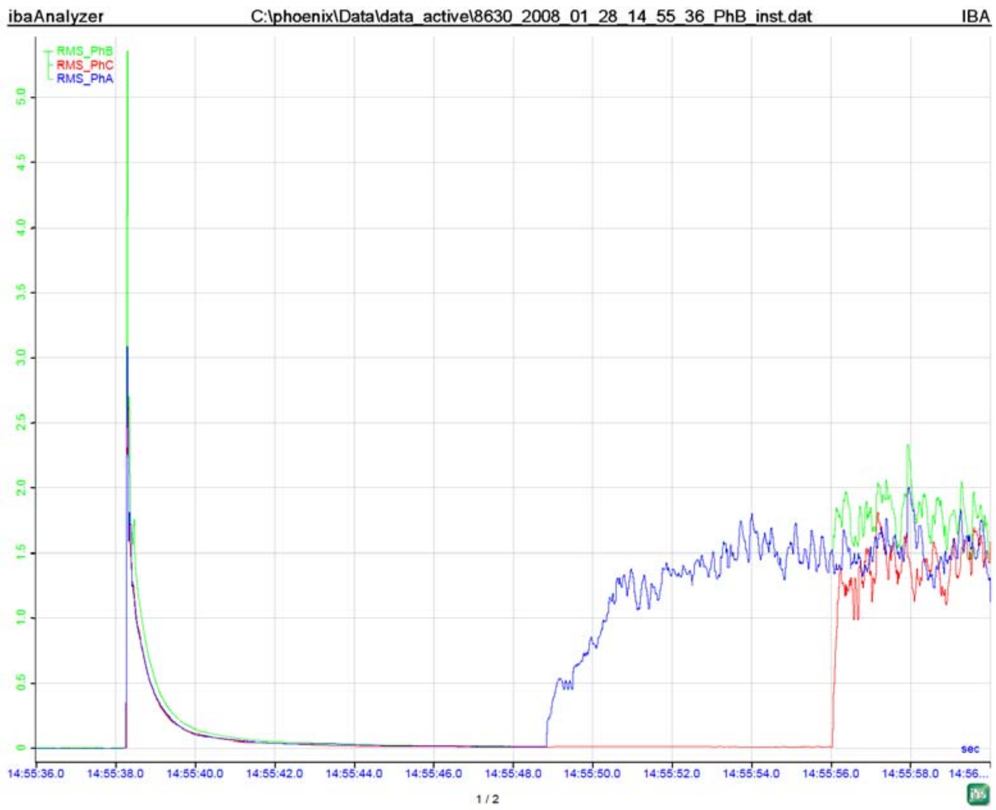

Figure 3. Inrush current example captured automatically with our new meter (1m-sec)

After taking a look at the many features defined for our new meter system, it was quickly realized that it did not exist as an integrated unit. All features could have been provided utilizing available hardware, but the integration of all features could not have been done in a portable fashion. This need for portability and future expansion capability drove us to pursue the in-house development of such a system.

The final results of our in-house efforts produced a synchronized and simultaneous multi-channel data acquisition front end with kilo-hertz sampling capability. The developed proprietary software for data analysis, HMI and data storage is all adequately housed in a standard "off-the-shelf" laptop computer.

Armed with this system, the technical engineer can now perform not only the traditional operational and electrical analysis but can also perform advanced harmonic and flicker analysis, regression and correlation analysis, and more. With these new capabilities our field personnel have provided customer specific power studies which have led to primary circuitry modifications and improvements, as well as determining the optimum operating set point for maximum power input leading to shorter power on time per heat.

THE USE OF THE NEW PHOENIX^{TM} PORTABLE ARC FURNACE ANALYZER

By using the previously introduced equipment along with other monitoring devices installed at the melt shop from our case, several analyses were performed in order to define the best route to follow from the use of power and regulation settings points of view.

We have already displayed several power and current intensity trend charts or heat profiles produced with the information collected with our monitoring equipment; we were also able to record several cases of scrap cave-ins in a fast data collection mode (1 ms period) to evaluate the severity of such kind of events when present.

Going back to our study case presented at the beginning of this paper, one interesting point about this operation was the fact that during part of this optimization process the melt shop went through some low voltage / high line-impedance instances that dictated the need for "less aggressiveness" in the regulation settings due to the presence of deep voltage dips at the time the regulator sent the electrodes down in search for their melting arc voltage set point.

With the real-time trending features we were able to monitor on-line the changes to the regulations settings and the interactions with the EAF operation parameters.

CONCLUSION

By using the experience of the melting personnel, in combination with our expertise and improved monitoring capabilities, it was possible to significantly improve the operation in this melt shop.

At the end of the optimization process the average power-on time was reduced from an approximate average of 33 minutes per heat, down to 29^{+} minutes per heat. This successful effort was conducted by several people from within the melt shop's operation as well as outside.

Besides the economic benefits attained at the end of this optimization process, one other very important lesson was learned. The combined effort amongst the various melting crews providing open and positive feedback on the EAF operation at the time of the adjustments, along with the proactive attitude of the support personnel (maintenance, process engineering, etc) were instrumental in achieving these impressive performance figures in a melt shop that was already in a prominent position in our EAF Worldwide Electric Arc Furnace Performance Benchmarking.

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