BADISCHE STAHL-ENGINEERING GMBH
Excellence in Steelmaking

The Time Balance of the Electric Arc Furnace

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To generate a correct and accurate EAF time balance is of high importance for the management of EAF meltshops. The time balance contains the information about the utilization and makes the production process and its interruptions transparent. However, many steelplants worldwide do not seem to use a concise and accurate time balance to control their process. This paper explains the concept of a systematic time balance of the EAF process as an example for all other steelplant processes (LF, Vacuum treatment, Casting) and the necessary delay recording which is an important part of the time balance.

Dipl.-Ing. (FH) **Dirk Riedinger**, Senior Engineer
Dr. **Andreas Opfermann**, Senior Metallurgist
Badische Stahl Engineering GmbH, Kehl, Deutschland
Alexander Vogel, Division Manager Control & Automation
BAG GmbH, Kehl, Deutschland

References

[1] Riedinger D., Hetzel R., Dr. Fleischer M., Hagemann R.: „Conceptual Basics and Excellence of Maintenance in Minimills“, MPT 5 (2008)

Concept of the EAF time balance

The typical Minimill liquifies metallic input material, modifies its composition and then solidifies the resulting steel for further processing.

To achieve the goal of an ideal supply chain where all aggregates, which are

- Raw material supply
- EAF
- Secondary metallurgy (e.g. LF, vacuum treatment)
- Casting,

run with full utilization, the capacity of these aggregates must principally be sized according to **Figure 1**,

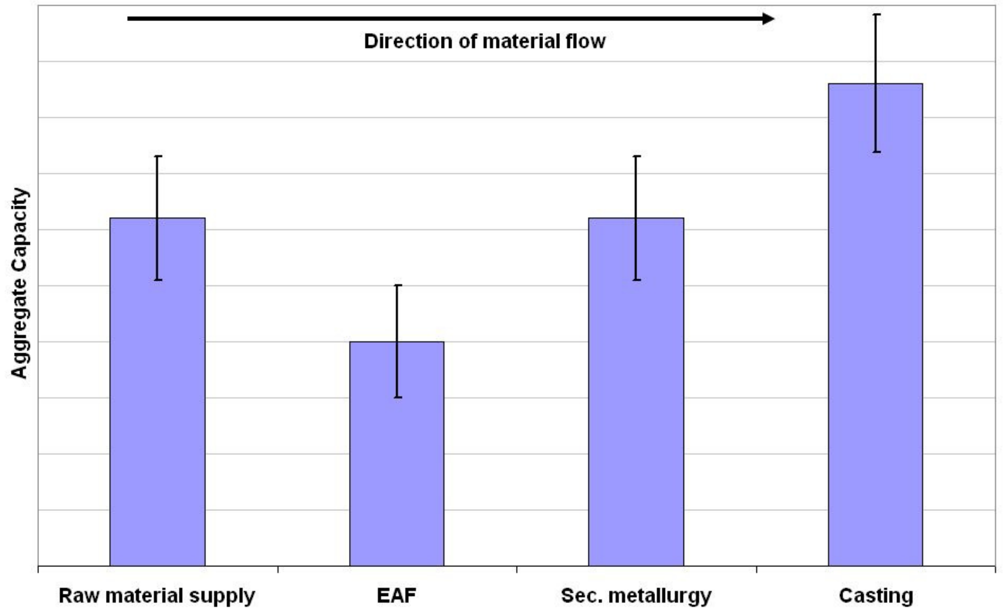

Figure 1: Ideal steelplant supply chain (qualitative)

which indicates that viewn from the EAF the downstream processes must be able to pull more material than the preceding upstream process supplies considering fluctuations. If this is not the case then bottlenecks appear and the utilization decreases. The upstream process of the EAF (the raw material supply) must be able to supply more material than the EAF can process. Then no waiting time appears.

Each one of the steelplant processes has peculiarities and difficulties. To control the whole process - the concert of the aggregates - is even more complex. The highest complexity can be found in plants which have mixed process routes (no straight and separate process lines respectively).

The goal is to achieve highest utilization for highest production output. To accomplish this goal, a continuous improvement is necessary in order to minimize unavoidable delay and shutdown times, to optimize setup times and thus to achieve excellence in operation and maintenance. In turn the continuous improvement is only possible if reliable information is available which provides transparency of the processes. This kind of information is contained in the time balance of each aggregate. The concept of a systematic time balance shall be explained for the Electric Arc Furnace because it is the most capital intensive aggregate. The time balances of the other aggregates are structured similarly and consider their different purpose, function and context. The Electric Arc Furnace requires a tailored time balance which is reflecting the melting process. This is presented in three complementary forms in **Figures 2a to 2c**.

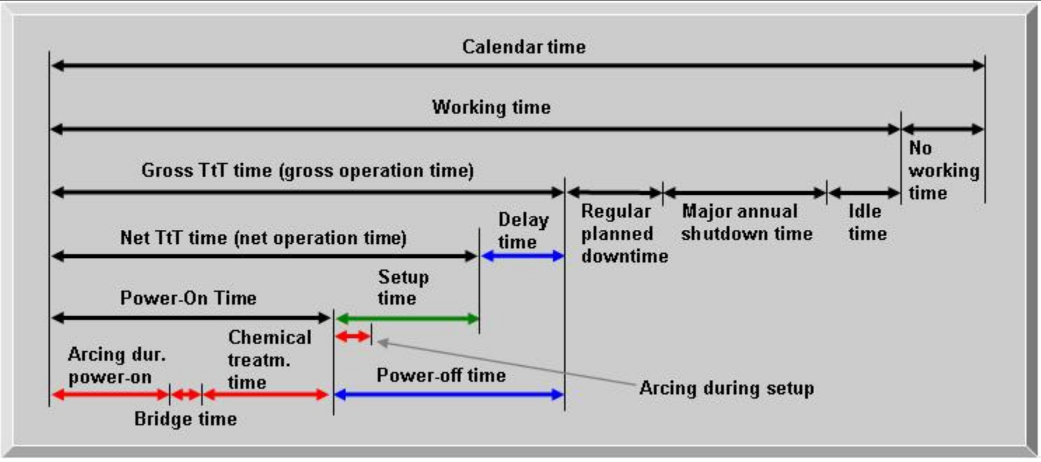

Figure 2a: EAF time balance #1

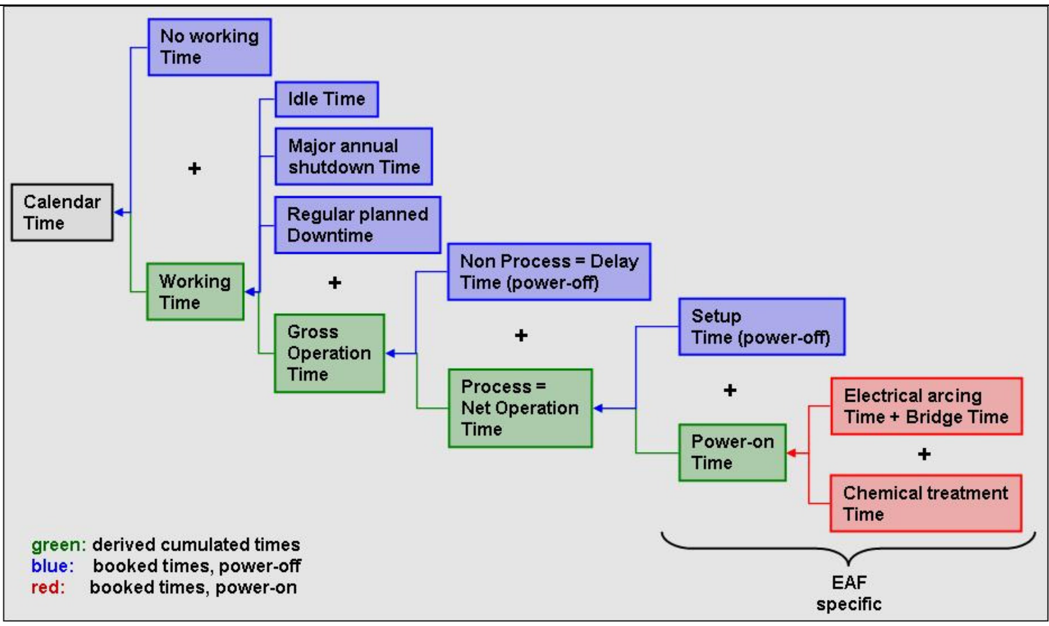

Figure 2b: EAF time balance #2

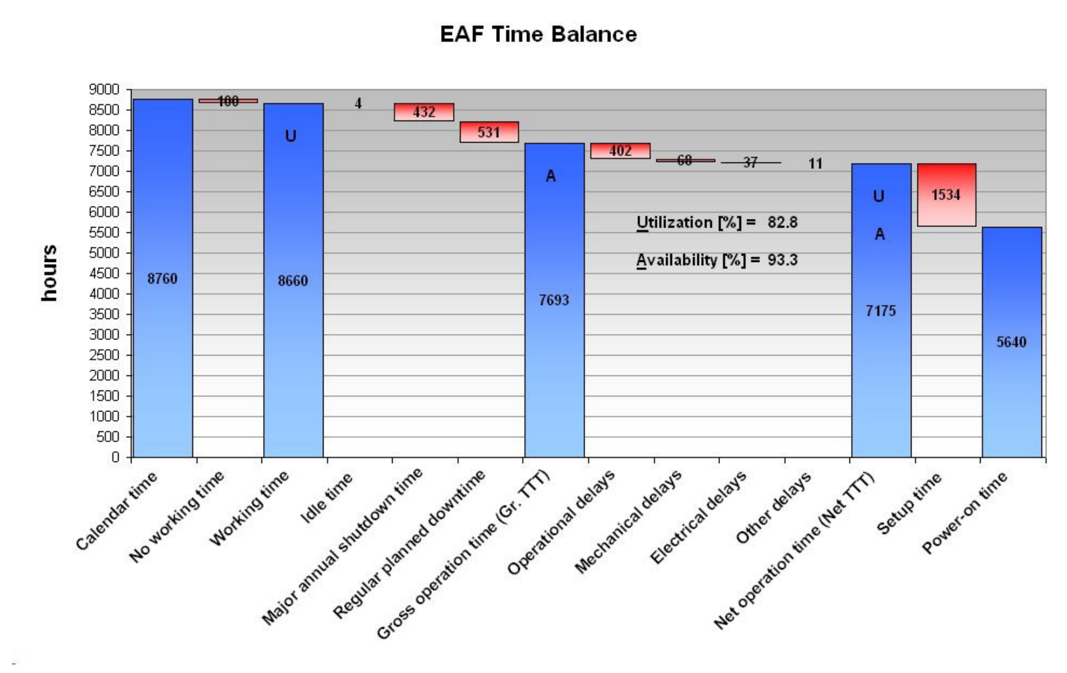

Figure 2c: EAF time balance #3 (exemplary)

A meltshop with more than one arc furnace needs a time balance for each one. Also for twin-shell arc furnaces a separate time balance for each shell is benefitial. The main purpose of a twinshell furnace is to maximize the arcing time. When shell A starts tapping, shell B can already start melting. Arcing and setup run in parallel. The twinshell process becomes problematic, when one shell can not be operated and the twinshell process is interrupted. Then the active shell must be regarded as a conventional furnace. Thus a separate time balance per shell makes sense.

The general EAF time structure is defined as follows. The calendar time is divided into categories which represent the typical EAF process conditions. Thus the important key performance indicators can be easily derived for process control.

Calendar time. The EAF time balance cumulates towards the available calendar time. This is the fix point.

No working time can be time where it is not allowed or not possible to work by law or by agreement.

Working time is simply calendar time minus no working time. It is time where the workforce is available. It can also be designated as the "adjusted calendar time".

Idle time is time where EAF operation is stopped due to reasons like e.g. power contract limitations or market restrictions.

Major annual shutdown time is usually the time where major overhauls or capital projects are carried out. It makes sense to distinguish between these irregular and e.g. weekly regular planned shutdowns to get a clear picture where the time for planned maintenance is consumed.

Maintenance carried out during idle time is a hidden time and must be recorded separately. It does not contribute to the time cumulation.

Regular planned downtime. The regular planned downtime contains - e.g. weekly - maintenance activities which require EAF downtime. For many reasons regular planned downtimes of the EAF process are necessary to achieve lowest equipment related delay times [1].

Gross operation time. By subtracting the total planned downtime and idle time from the working time, the gross operation time is derived. This is - in principle - the time available for furnace operation. It is also the cumulation of all EAF cycle times per year. The EAF cycle time is the gross Tap-to-tap time. This is usually the time from end of tapping to end of tapping. It is called *gross* Tap-to-tap time because it includes all delays caused by operational or equipment problems.

Delay time. This is representing the time where the EAF process is interrupted for unplanned reasons. In contrary to the idle time the delay time is unexpected. The total delay time is usually split into operational, mechanical, electrical/electronical and other (miscellaneous) delays. Different additional split-ups are possible.

Net operation time. The net operation time is the gross operation time minus the total delay time. It is the cumulation of all net Tap-to-tap times and thus is pure process time. It contains

- Power-on time and
- Power-off time that is required to run the EAF process.

Setup time. This process power-off time is cumulated from all activities which maintain the EAF process but which need to be conducted when the EAF is stopped (during power-off). It contains activities like

- Tapping
- Turnaround
- Electrode change or slip
- Charging (scrap, hot metal, etc.)
- Refractory maintenance (e.g. gunning, spinning)
- Sometimes temperature and sample taking (if during power-off)

Power-on time. The power-on time is defined as the net operation time minus the setup time. It contains

- Electrical arcing time,
- Bridge time and
- Chemical treatment time.

The arcing time is the time where electrical current is flowing that is higher than a threshold (e.g. 5 kA for 1 sec.). Arcing time can appear during a setup time (e.g. arcing during tapping). Then it is a hidden time running in parallel and not contributing to the time cumulation. It is therefore necessary to record the arcing time independently from the power-on time to be able to calculate the correct average primary active power input into the EAF, which is

Primary Active Power = El. Energy Cons. / Arcing Time

$[MW_{primary} = kWh / 1000 * 60 / min_{arcing}]$

and thus to derive the transformer utilization and melting efficiency. For accuracy reasons the kWh-value per impulse coming from the electrical energy counter should not be too large. A value of 10 to 25 kWh per impulse is a good value.

The bridge time will be explained with the delay recording concept.

The chemical energy input time is a feature of special arc furnace processes like the Conarc process with its twinshell furnace and oxygen top-lance where also the oxygen blowing time is considered a power-on time as it results in refining the steel, it is a chemical treatment time. „Normal“ Twin-Shell furnaces use a scrap preheating period. This can also be considered as a chemical treatment time. Like the arcing time the chemical treatment time must be derived from process signals (oxygen flow or a similar reliable signal) using a threshold.

It is important that the time measurement is accurate. Each second counts. Only then am accurate and reliable time balance can be generated.

The time balance must be interpreted as a cumulative time measurement. The shorter the power-on time and the tap-to-tap time, the more heats are produced per year (under identic conditions). The goal is to achieve as many cycles per year as possible (maximal EAF production).

The time balance does not indicate losses in speed directly, e.g. when the melting time is prolonged by some reason. This results in longer tap-to-tap times and thus in less cycles (number of heats) and less throughput (t/h) per year.

With the discussed split-up of the calendar time the time balance provides the important key performance indicators describing the EAF process, which are

- Utilization
- Availability
- Delay rate
- Setup rate
- Power-on rate

at a glance.

The utilization is the quotient of net operation time and working time. It is indicating how much of the available time is used for operation. The goal is a maximal operation time, thus an utilization close to 1. In reality planned shutdowns will be necessary to maintain wearing equipment and also unexpected interruptions can not be avoided. Optimal maintenance minimizes planned and unplanned shutdowns [1].

The availability is the quotient of net operation time and gross operation time. It is indicating how much of the operation time is lost by delays. The goal is again minimal delays and thus an availability close to 1. The availability will always be greater than the utilization as it does not consider the planned shutdowns and idle time.

The delay rate is the quotient of delay time and gross operation time. It indicates how much of the tap-to-tap time is delay time and should be minimal.

The setup rate is the quotient of setup time and gross operation time. It indicates how much of the tap-to-tap time is setup time. Smaller values indicate better operational performance.

The power-on rate is the quotient of power-on time and gross operation time. It indicates how much of the tap-to-tap time is power-on time. The higher the power-on rate, the better.

Badische Stahlwerke GmbH (BSW), one of the most productive Minimills of the world (2x90MVA, 39,1Nm³/t O_2, 93,3t tapping weight, 100% scrap charges, 73,3 Heats/day), has an average gross tap-to-tap time of 39,32min. **Figure 3** shows its split-up (average values of 2007 and 2008) as an example and indicates a highly optimized and standardized EAF process. The utilization is about 83%, the availability is >93%.

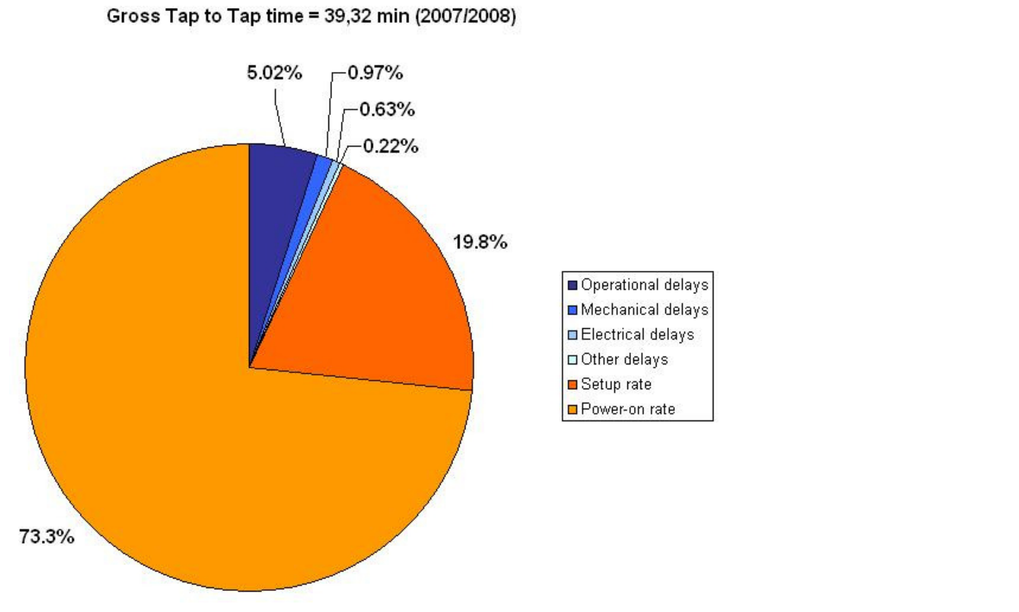

Figure 3: Split-up of the average gross tap-to-tap time at BSW

An excellent niveau for maintenance delay rates is less than 1% for electrical and less than 2% for mechanical delays [1].

The delay recording concept will be explained next. It is the basis for a precise time balance and for transparency of problems which disturb EAF operation.

Concept of the EAF delay recording

The delay recording system serves mainly two objectives. One is to build the accurate time balance. The other is to record what kind of delay has appeared. The problem area and the reason of the delay are recorded and stored in a data base for further evaluation and automatic report generation.

The delay recording system therefore provides transparency for problem identification which is the basis for optimization measures.

As mentioned, the time recording must be very accurate, every second counts. In many plants the time balance is still recorded manually by the furnace operator. This practice reduces the time accuracy to the minute level and is open for manipulation because it does not provide a reliable frame derived from process signals. A reliable active power calculation is also impossible. Furthermore, the manual recording on a sheet of paper makes it very hard to evaluate the delays. This is even more difficult if no code system is used for the delay area and reasons. Free text is not evaluable in an automized manner. The required time and resource for evaluation is far too high. The result is intransparency of the process and of the problems. Manual time recording is not objective and not reliable. These problems indicate that the time recording must be automized. It must be derived from process signals processed by the furnace PLC. The required signals are:

- kWh impulse
- Power-on signal derived from electrode current(s) / media flow
- Tapping signal (=end of heat, start / end)
- Charging signal for scrap, hot metal, etc. (start / end)
- Pre-heating signal (start / end)

The EAF process is in power-off mode when the power-on signal is off and the bridge time is over. This time (e.g. 20 sec.) is closing gaps that are too short to be called power-off. It represents process conditions like short circuits with subsequent arc extinguishing caused by cave-ins of scrap and is necessary to avoid too frequent delay input requests. The bridge times are cumulating and have to be recorded as power-on times.

The system itself can not distinguish between a delay time and a setup time, both are power-off times. Therefore the power-off time must be designated by the furnace operator who must choose the code which describes the correct reason for power-off. Only setup times like tapping, charging and turnaround can be calculated by the system automatically from the process signals and some logic.

For the setup times it is necessary to define time frames, so called *Standard Setup Times* (SST). This is required to be able to define the point where a setup time has been exceeded and therefore ends and the delay time starts.

Example: when charging of the first basket has been done and the required time for charging was within the SST frame and the EAF was powered on, the system will record the needed setup time for charging. If the standard charging time was exceeded then the system will record the SST, request a delay code input and will then record the delay time until power-on. During furnace operation (power-on) each power-off will result in a delay input request by the system. The operator has to decide if it is a delay, a setup time, a planned shutdown, or an idle time.

To be able to evaluate the delays by category and reason (cause), it is necessary to have a code system for the delays which contains the problem area or category and the primary reason. The reason is called primary because it is often difficult to know the root cause immediately. Three main types of codes have to be distinguished, which all describe power-off times:

- Functional delay codes
- Operational delay codes
- Standard setup times (SST)

Planned shutdowns, idle time and no working time are separate superordinate codes.
The functional delay codes represent functional failures of equipment. They are connected to the equipment (or asset) structure of the plant and thus to the responsible maintenance department (electrical / electronical and mechanical). The code system should provide some main groups which are further divided into sub-groups. The division must not be too detailed. The delay recording is not a maintenance tool for detailed analyzations. It provides a rough but clear picture of where and why the problems (EAF process interruptions) happen. Then maintenance must investigate in more detail if problems are frequent in a certain area.
The operational delay codes represent operational problems like a broken electrode or waiting time due to logistical problems or metallurgical peculiarities.
The standard setup times (SST) have to be defined and are used to check if the EAF process is performed optimally. They should be set in a way that the standard time can be achieved in average (even gaussian distribution). If the process time is always shorter or longer than the standard time, then the value is too large or too ambitious.
The code system allows to evaluate not only by time but also by frequency of occurance. The delay distribution of time and frequency is usually not the same, therefore both have to be evaluated. One big delay time may occur once per year but many small delay times accumulate. Using a Pareto analysis as the basis for a structured problem solving process (**Figures 4 and 5)**, the most disturbing problem areas can be easily found. These „vital few“ areas or equipment categories which cause 80% of the delay time or frequency can then be investigated further. The goal is

- to find a solution for the problems and
- to avoid recurrences and
- to document the development of the problem areas.

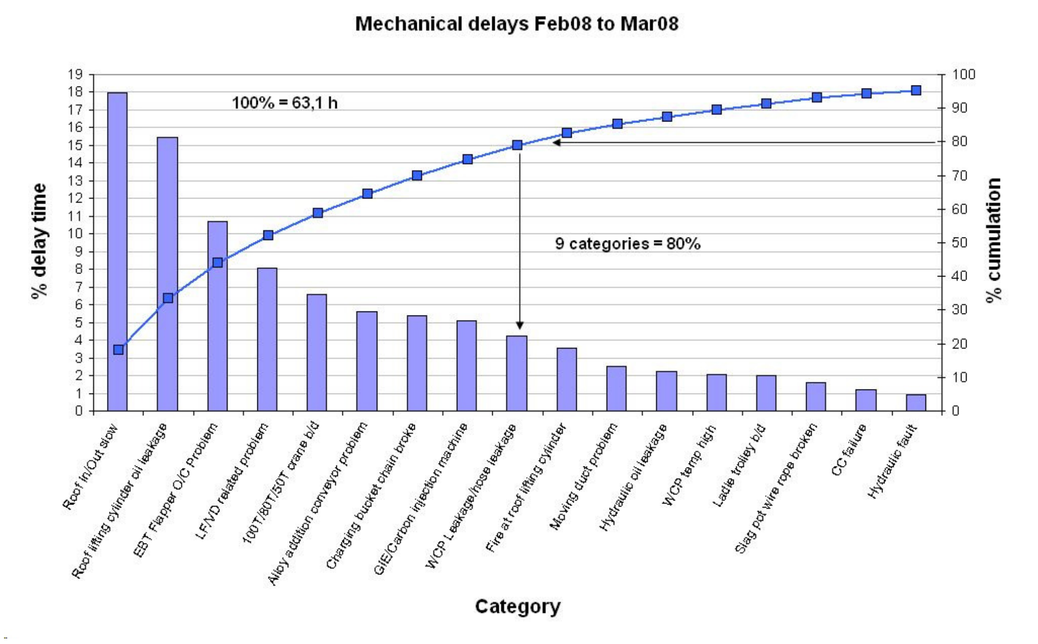

Figure 4: Example of a Pareto analysis by delay time

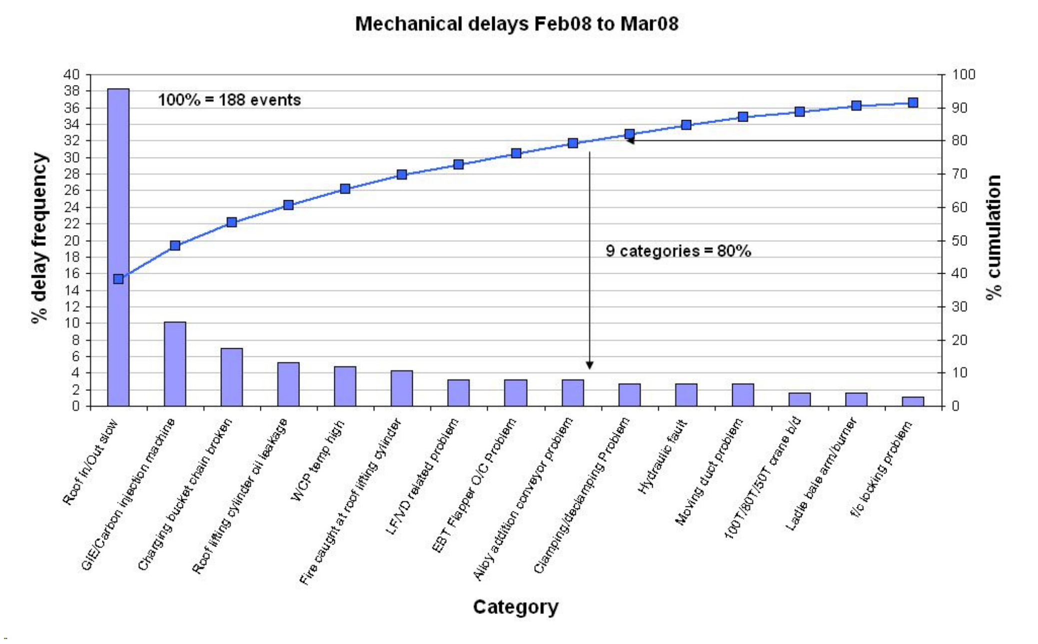

Figure 5: Example of a Pareto analysis by delay frequency

Experiences

Many plants do not operate a precise and automated time recording and reporting. But every plant is recording process times. The argument for an automated system especially at the EAF is simple. As process times are recorded anyway, they should be recorded accurately to get a clear picture without distortions. This is a requirement for achievement of best utilization and continuous improvement of the production process. The potentials for improvement are large as the EAF is the most capital intensive part of the steelplant.

Often the time recording is incorporated in a L2 automation system. In fact it is a L2 function. But many plants do not have this automation level or have not started it or it does not function in a satisfactory way. In that cases a separate time recording system makes sense because it is comparably cheap, uncomplicated to install and of small delivery time. The costs are small compared to the benefits.

The automated time and delay recording seems to be quite simple. But also here the devil hides in the details. It is benefitial to use a professional system which provides flexibility (e.g. code system is easily adaptable) and standardized information contained in a data base. BSE and BAG jointly have developed such a system, **Figures 6 and 7** show it's "Time Code" and "Time Logging" HMI mask.

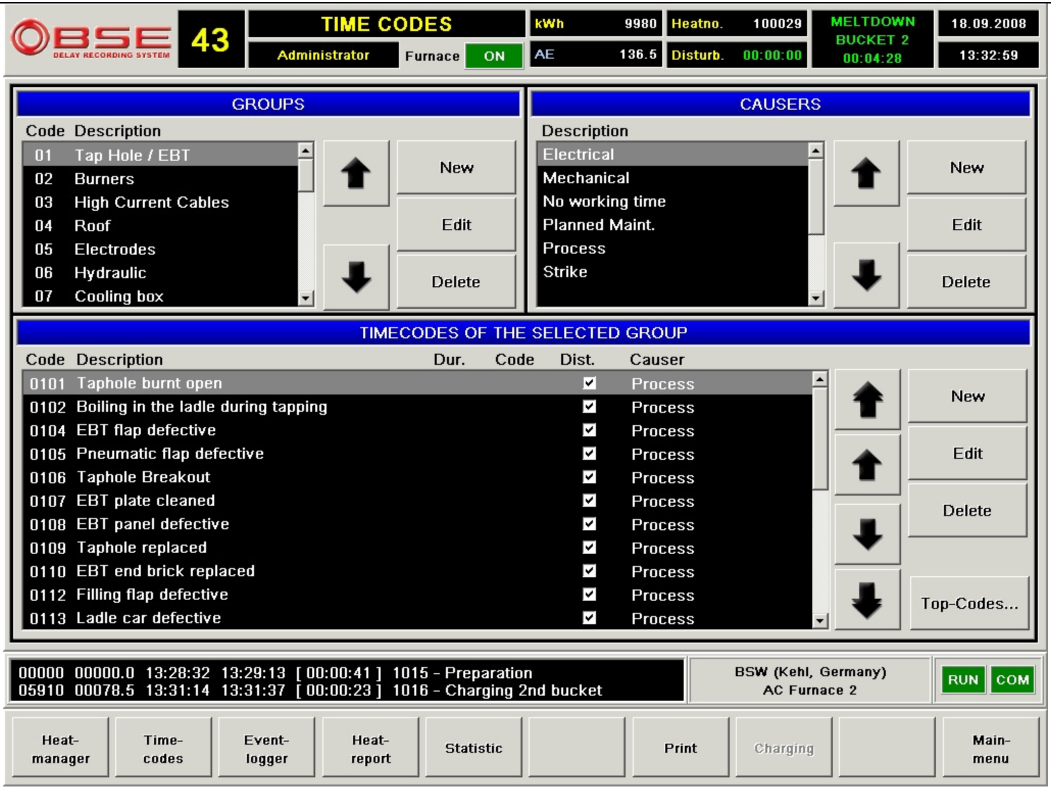

Figure 6: Time Code mask of the BSE delay recording system (DRS)

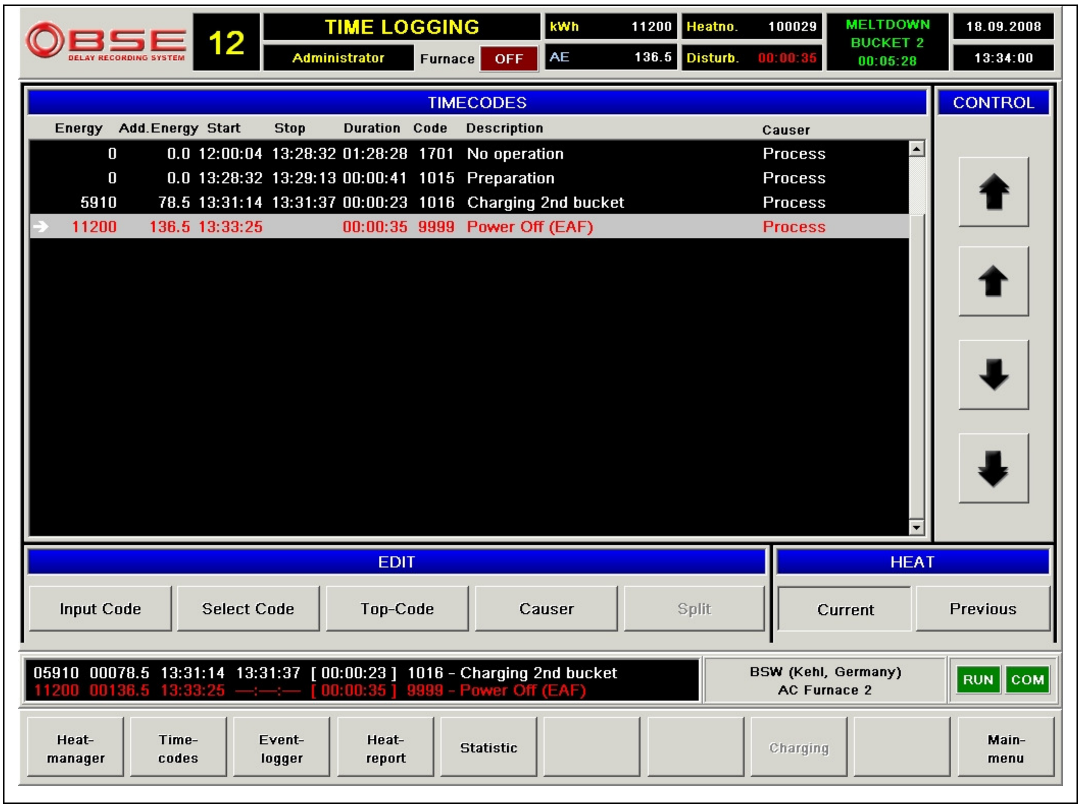

Figure 7: Time Logging mask of the BSE delay recording system (DRS)

Often the concept of the described systematic time balance is not respected. Some examples will indicate according problems.

Case 1. A standard tap-to-tap time is defined for a certain melting process. If the process changes and the tap-to-tap time increases (e.g. due to longer melting time) then the additional process time (which is power-on time) is declared as a delay time. Obviously this kind of time recording leads to total intransparency of the process.

Case 2. Power-on time, setup time and delay time are not clearly distinguished in the time recording. Then a correct calculation of the utilization is impossible.

Case 3. The arcing time (power-on time) is measured by evaluating the position of the furnace breaker. This is not accurate as often the breaker is still closed without arcing. The arcing time becomes too long and is not matching the energy counter (kWh consumption) any more. The calculation of active power and of transformer utilization is wrong.

Case 4. Standard setup times are not defined or the meaning of setup times are not reflected in the time recording. An important lever for process optimization is not used as often the setup times are not at all optimized. Process time is lost.

The importance of having a systematic time recording has been pointed out. But the results generated by this system are only as good as the inputs by the operators. The delay recording requires discipline of the persons who input the delay codes. It is a management responsibility

to explain the importance and to enforce an accurate delay recording. Ideally the delay code chosen should be close to the real cause. If the cause is not clear then electrical and mechanical maintenance should give feedback. It makes anyway sense that electrical and mechanical maintenance appear together when an equipment problem is unclear.
It must be known to everybody that the delay recording and analysis is not performed to blame each other but only to reveal and exploit the optimization potentials. It is a management task to find out the real problems by asking the right questions and then taking the right decisions based on a systematic reporting.

Conclusion

An accurate time balance is the backbone of a transparent EAF process. It is substantial to know exactly where and why process time is lost. Management is not so close to the process as the shift workers and needs reliable and systematic process information documented in reports to control the process. It is not always obvious where time is lost unless it is precisely documented. As a matter of fact manual recording is not precise enough. Insufficient transparency results in unused optimization potentials and is counterproductive. The goal must be highest process transparency for highest production output.