

PROFESSIONAL ARTICLE

# EFFICIENCY CALCULATION

## COST-EFFECTIVE PROCESS CONTROL IN FOUNDRIES

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## INTRODUCTION

The upward trend in personnel, energy and starting material costs makes it necessary to utilize resources in production ever more efficiently. Improved quality control and process control, with the effect of reducing rejection rates and increasing capacity, is one possibility for boosting efficiency in foundries.

The present article demonstrates that process control in the form of continuously analyzing the chemical composition of molten aluminium not only yields advantages from the technical viewpoint, but can also be applied cost-efficiently or even profitably from the economic angle.

The solutions currently applied as means of inspecting aluminium during production, such as spark-optical emission spectroscopy (spark OES), involve a considerable amount of running costs that are not necessarily apparent at first sight. Besides the actual analysis equipment, there is a need for additional apparatus to prepare the test samples and automate the procedure. The creation of infrastructure, for instance air-conditioned premises, also leads to extra costs. And carrying out the sampling, calibration and measuring itself represents a not inconsiderable, current cost factor.

The aim of the present article is to sharpen awareness for cost control in quality assurance and for the fact that the solution implemented at present is often more expensive than is assumed. From this viewpoint it also pays under certain circumstances to make a larger, one-off investment that is characterized by lower running costs, entails a shorter payback period and offers savings potentials.

The article focuses on illustrating the cost-effectiveness of a measuring instrument that is based on a measuring principle referred to as Laser-induced Plasma Spectroscopy (or LIPS for short) and is used for continuous in-process control of molten aluminium.

## PROCESS CONTROL

In addition to conventional in-process analysis by means of spark-OES there are, meanwhile, measuring instruments on the market that analyze the chemical composition of molten aluminium contactlessly. Process control can hence take place directly, without sampling in the molten metal. This is made possible by the use of the mentioned LIPS technology. LIPS offers the major advantage of instantaneous, contactless measurement of the alloying elements in the molten metal.

The measuring principle (Figure 1) is based on a laser, which emits short, intensive pulses of light. These are conducted via a light-guide system to the molten aluminium, where they impinge in focused form on the melt. The high power densities cause several micrograms of the molten metal to "vaporize". Because of the extremely high temperature, it is not vapour in the conventional sense that is generated but a plasma comprising highly excited atoms, ions and electrons. This plasma, in turn, emits light in certain frequencies that are characteristic of individual chemical elements, representing

a type of "fingerprint" of the molten aluminium. It is thereby possible to determine the concentration of elements such as silicon, magnesium, copper, iron, etc., i.e. to analyze the chemical composition of the melt quantitatively.

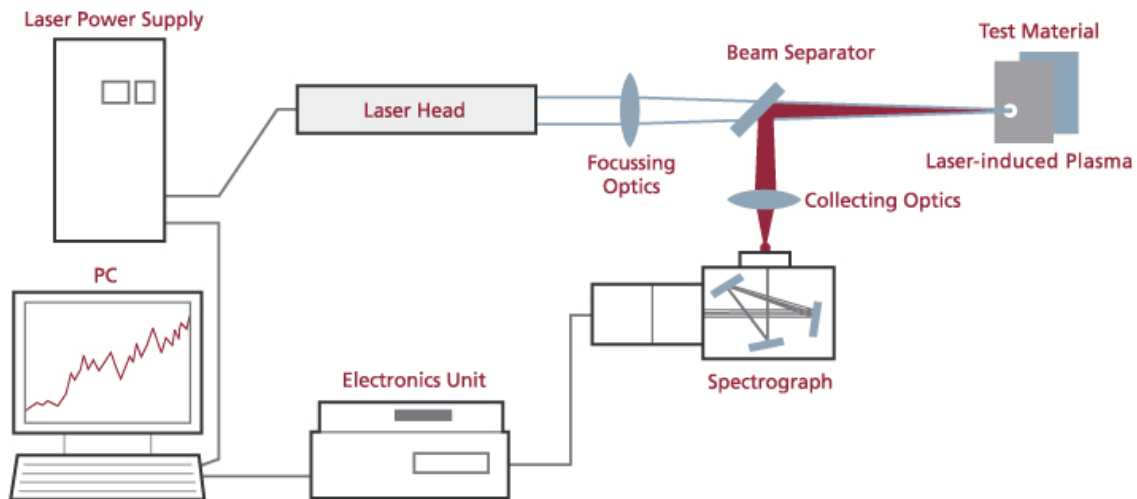


Figure 1: Principle of Laser-induced Plasma Spectroscopy (LIPS principle)

The fact that the technique is contactless and the measuring systems are industry-tested (aluminium, minerals) enables LIPS equipment to be used in places where conventional methods are unsuitable. LIPS offers vital advantages over the normal analysis method, especially under extreme conditions such as the melting and casting of aluminium in production shops. The rapidity of the measurement permits continuous control of the melt without any sampling. The uncertainties of sampling and solidification are eliminated through the direct, in-melt analysis. The resulting data are output locally and in real time, thus making real in-line process control possible.

## INITIAL BASIS

Described in what follows is a cross-section of the experiences and findings from the foundries which the authors visited. Numerous discussions with experts and producers of cast and wrought alloys from the German-speaking area, as well as production data and specialist literature on the topic of aluminium recycling, formed the basis for carrying out this efficiency calculation.

To start off, an overview of a foundry enterprise's key data is given, in as far as they are relevant for quality control. This constitutes the initial basis for the economic efficiency analysis in the subsequent chapter. Particular attention is paid to the derivation of the costs remaining logical and comprehensible.

## Days of production

Foundries normally operate a 3- or 4-shift regime, with eight hours per shift. A differentiation is consequently made according to both variants in the efficiency calculation.

Working a 5-day week and 50 weeks of production per year adds up to 250 days of production (assumption: 3-shift operation). Working a 7-day week (assumption: 4-shift operation), by comparison, adds up to 350 days. Downtime or repairs and maintenance work reduce this number by an estimated 10 %. What then remains, effectively, are 225 days of production in the first case and 315 days of production in the second as a basis for the further calculations.

## Process

Looking at the process, it is basically possible to differentiate according to continuous operation and batch operation. Numerous variants or combined forms of the two process types have been used successfully, in addition. While continuous operation means uninterrupted melting and casting of alloys over a prolonged period, the normal practice in batch operation is to melt and cast the aluminium in particular units or batch sizes that are mostly limited by the furnace capacity. The cycle time in batch operation ranges in most foundries between four and six hours. For this reason, batch operation with a cycle time of five hours is assumed for the present calculation, meaning that an average of 4.8 batches are processed per day.

## Quality control

The current practice of in-process control involves taking a sample from the molten metal and then analyzing it in a laboratory. This has so far been the only sufficiently accurate possibility to obtain relevant information on the chemical composition of the aluminium melt relatively quickly under arduous foundry operating conditions. Two factors are crucial for assessing the associated costs: the number of samples removed and measured, and the time taken in each case for the sampling and analysis.

### Frequency of quality control

The answer to the question of how many samples are actually taken during the entire melting and casting process depends on, among other things, such factors as the starting material (in-plant returns, purchased scrap), the work processes involved, the alloy and, of course, the product itself.

At first glance it appears that only few analyses are made in the foundries to monitor the quality. Sampling at the start, mid-point and end (SME) of the casting process ensures, for the customer, that the foundry man adheres to the alloy specifications (analysis certificates). Upon closer examination of the work processes it is found that a number of other verification measurements are carried out in the various foundries in addition to the SME sampling, for instance in the melting furnace, in the pouring and hold-

ing furnace, in the launder, at the impeller station, before the start of casting, etc. These samples are generally removed for verification purposes or for the approval and release of the material for the next process step.

Given the great number of work processes, it is not easy to establish an average value for the number of analyses per batch. A number of five samples per batch is assumed for the efficiency calculation in this article. In many enterprises the number is (much) higher, but in hardly any enterprise is it lower. In most cases, one or more control samples are also taken prior to the actual casting which are analyzed locally in the foundry laboratories. If there are any difficulties, additional analyses are carried out. Five samples per batch are therefore a cautiously estimated value from the viewpoint of the authors.

### Duration of quality control

A survey conducted in the foundries as to how long in-process controls take was very informative. The sampling itself begins with the preheating of the sampling spoon. In addition, there are a number of other work steps that are necessary in order to obtain a chemical analysis. These steps, including the time taken in minutes, are shown in Table 1.

The finding of the survey was that, despite extensive automation, between 12 and 15 minutes pass from the start of sampling until the analysis is available. This finding has already been verified several times by observing or timing the individual work steps in different foundries. If the weekly cleaning effort is additionally calculated, the time required for one sample averages **15 minutes**.

Average time requirement: sampling and analysis		
Work step/ activity	Working time	Units
Sampling	3.0	min
Transport to laboratory	2.0	min
Preparation/ handling of sample	2.0	min
Cleaning + calibration prior to measurement	2.5	min *
Spark eroding of sample	2.0	min
Evaluation and assessment	2.0	min
Regular apparatus cleaning	1.5	min **
<b>Duration of sampling + analysis</b>	<b>15.0</b>	<b>min</b>
<i>* Assumption: 1 hr. cleaning + calibration/ day</i>		
<i>** Assumption: 3.5 hrs. Cleaning/ week</i>		

**Table 1: Sampling + analysis time**

## EFFECT OF INVESTMENTS ON PERFORMANCE

### Quality control

During the research to determine the analysis costs actually incurred in foundries, the authors got to know several calculation variants. These range from an overall representation of the analysis costs per sample, to stating the analysis costs per minute. The costs are mostly in the order of around 20 euros per sample, or 1.40 euros per minute of analysis. The figures include overheads. The authors do not include any such data without verification. In what follows, their own derivation of the quality control costs is described.

Several work areas or teams are involved in carrying out the in-process controls. On the one hand, there is the foundry personnel, who remove, mark and, in some instances, spark-erode the sample themselves. And on the other hand, there is the personnel from the foundry-run or central laboratory that receives a part or all of the samples from the foundry. There are also various analysis instruments in either the foundry-run or the central laboratory. The instruments in the central laboratory are used in most cases not only for the ongoing monitoring of samples, but also for other analysis purposes (analysis certificates, investigation of complaints, R&D, etc.). When determining the costs incurred in quality control, it makes sense from the viewpoint of the authors to differentiate according to analysis costs and personnel costs.

### Analysis costs

Understood by analysis costs are those costs incurred purely through the procurement, maintenance and operation of the equipment for chemical analysis, sample preparation and accompanying automation purposes. These costs must by all means be included in the efficiency calculation. The costs incurred for the fitting-out of the foundry-run or central laboratory in this connection are subsequently taken into account in the overheads.

#### Calculation:

Assuming that the cost of procuring analysis equipment and of sample preparation amounts to a net total of 110,000 euros, then the sum total, based on a service life of eight years (depreciation/capital allowance) together with the annual maintenance costs of 6,500 euros, is 20,250 euros per year. With a throughput of five samples per batch, i.e. 24 samples per day and an average of 6,480 samples per year, the analysis costs incurred amount to 3.13 euros per sample. This, however, includes neither personnel nor overhead costs.

Although LIPS technology-based inline process control does not replace conventional in-process analysis, it does however reduce the number of sampling operations and analyses. A minimum of samples is needed in foundries for reference purposes or for analysis certificates. If it is assumed that at least two from five samples need to be taken (at the start and at the end of the casting process), this means a savings potential of three

samples per batch. Taking the analysis costs of 3.13 euros per sample as a basis, the saving in samples per day, calculated to be 14.4, reduces the analysis costs by 45 euros per day (Table 2). Multiplied by the two values for the days of production, i.e. 225 (3-shift operation) and 315 (4-shift operation), this amounts to 10,125 and 14,175 euros per year, respectively.

Item	Basis	Description	3-shift operation	4-shift operation
<b>Analysis costs</b>	€ 3.13	Analysis costs/ measurement		
	14.4	Sampling savings/ day		
	€ 45.00	Analysis cost savings/ day		
		Cost reduction per year	€ 10,125	€ 14,175

**Table 2: Impact of analysis costs on performance**

Whereas a reduction in the number of samples leads to higher sampling costs being incurred for the already used analysis technique, this cost increase is offset by a longer service life of the equipment and by lower service and maintenance costs. It can therefore be assumed that the lower number of samples, on the one hand, and the prolonged useful or service life of the analysis equipment, as well as the reduction of the servicing and maintenance costs, on the other hand, keep the costs per sample for the conventional analysis technique more or less constant, when all said and done.

### Personnel costs

According to a study by the Austrian Federal Economic Chamber dated September 2006 [1], the gross monthly salary of a foundry worker in Austria averages 2,350 euros per month. Data from the Federal Ministry of Finance (BM) [2] show that annual labour costs per employee incurred as a result to employers amount to 43,170.91 euros including non-wage costs. The hours worked per capita in a foundry amount to 2,038 annually [1], of which 82.5 % are hours worked directly in production [1]. This means that a worker in the foundry industry works an average of 140.1 hours per month in production. Based on these figures, labour costs of around 25.68 euros are calculated per man-hour of production. This does not take any overhead costs into account.

#### Calculation:

If the stated hourly rate is apportioned to the sampling and analysis duration of 15 min, the resulting personnel costs per sample are 6.42 euros. Extrapolated in relation to the annual number of samples, the personnel costs incurred in quality control then amount to 34,663 euros (3-shift operation) or 48,528 euros (4-shift operation) per year.

Inline process control using LIPS technology eliminates the majority of these costs, since personnel expenditure is no longer incurred for LIPS analysis. The measurements take place automatically, without any sampling or manual intervention. Assuming a foundry

worker removes only two samples per batch, this means a saving of 14.4 samples or 92.43 euros per day (Table 3). Viewed over the period of a year, this yields a saving of 3,240 samples (3-shift operation) or 4,536 samples (4-shift operation). In terms of man-months this means an annual saving of 5.8 or 8.1 man-months, respectively, and, in monetary terms, 20,798 euros for 3-shift operation or 29,117 euros for 4-shift operation.

Item	Basis	Description	3-shift operation	4-shift operation
<b>Personnel costs</b>	€ 6.42	Personnel costs/ measurement		
	14.4	Sampling savings/ day		
	€ 92.43	Personnel cost savings/ day		
		Cost reduction per year	€ 20,798	€ 29,117

**Table 3: Impact of personnel costs on performance**

The argument that the stated cost savings do not simultaneously denote personnel savings, especially as the personnel are present anyway and are involved in the sampling and analysis work, is invalidated in that the lightening of the work burden for the personnel in the foundry has an important influence on the quality of the work. The elimination of "routine analytical activities" enables the personnel to concentrate more on the casting process itself. A lightening of the work burden frees up more time for other tasks (e.g. servicing of machinery), ultimately allowing the work to be shared differently among the personnel. In times of scarce resources and constant overburdening of the personnel, this constitutes a practical way to ease the workload, not only on the foundry shop floor, but also in the laboratory.

When using inline process control based on LIPS technology, it is possible not only to automate control of the casting process, but also to expand it through much shorter control cycle times – something which is more or less impracticable with current manning levels and the necessity for manual sampling. Additional process control analyses do not entail extra costs for the foundry or laboratory. Automated process control, especially during the night shifts when the laboratories are not usually manned, also help to reduce uncertainty and to increase process capability and process stability.

### Quality control costs

If the costs calculated with regard to analysis (3.13 euros) and personnel (6.42 euros) are compared, it is noticeable that the current personnel costs have a much greater bearing than the non-recurrent cost of procuring the equipment. Analysis and personnel costs added together amount to a sum of 9.55 euros per sample when carrying out (in-process) quality control. These costs do not include any overheads, however.

## Remelting costs

Rejected material is a topic that is not happily discussed outside the foundry. The fact is that material which has actually been rejected is remelted in exactly the same way as pure in-plant returns. While the aluminium is not lost, it does however entail additional costs incurred for remelting the NF metal.

### Calculation:

If 3 % of a foundry's annual production does not conform to requirements, for example, this can be attributable to various causes. Faults and deficiencies can arise in production at any time. Assuming that roughly 25 % of the 3 % rejection rate in the foundry are due to inadequate process control in respect of the alloy composition, this leaves a nonconformance rate of 0.75 %.

This nonconformance rate, when based on a furnace capacity of 15 t and a derived annual capacity of 16,200 t (3-shift operation) or 22,680 t (4-shift operation), generates an amount of 122 t or, respectively, 170 t rejected material per year. The rejected material is valued at an all-inclusive amount of 200 euros per tonne, representing the balance between input and output per tonne of material in the foundry.

The use of inline process control based on LIPS technology can reduce the amount of rejected material significantly. Continuous control makes it possible to identify in-melt deviations and trends in real time. The foundry worker thus has the opportunity to respond immediately and largely preclude nonconformance in production and products.

Reduction of the rejection rate alone yields considerable savings. The material does not require remelting, thereby saving the production costs that this involves. The increased throughput leads to a degression of the production costs per ton. Reducing the rejection rate also yields further cost advantages. Special reject material-related costs arising as a result of processing the material (crushing, storage, etc.), material shrinkage, and loss of quality during remelting, are avoided. The transformation of rejected material into a reutilizable product that can be sold at market prices additionally means an increase in turnover and, ultimately, in profits.

In order to take account of all the mentioned factors in the calculation, an overall factor of 1.25 is applied by which the amount of rejected material is multiplied. This, as Table 4 shows, reveals a cost reduction of 30,375 or, respectively, 42,525 euros annually.

The costs incurred due to non-conforming material from a foundry can rise still further, particularly if the non-conformity is not discovered until a later point in time. The more processing steps have taken place in the value chain, the higher are the costs already incurred. This aspect is not even considered at all in the present calculation, meaning that under certain circumstances the savings potential offered by inline process control is even significantly higher than is stated here.

Item	Basis	Description	3-shift operation	4-shift operation
<b>Remelting costs</b>				
	0.75%	Reject rate in the foundry		
	€ 200	Input/ output cost difference		
	1.25	Overall factor		
	15 t	Furnace capacity in tons		
		Cost reduction per year	€ 30,375	€ 42,525

**Table 4: Impact of remelting costs on performance**

The most unfavourable case for the manufacturer arises if the non-conformity comes to light only after the product reaches the customer. Customer complaints or (voluntary) withdrawal of the product from the market leads to considerable, unbudgeted costs. These also rank as avoidable costs in an efficiency calculation. In such a case, the total production costs must be entered as rejected-material costs, added to which there is a difficult-to-evaluate loss of image for the enterprise.

Not included in this calculation, either, is how much capital is tied up within an enterprise as a result of the rejected material that accumulates or the non-realization of additional production. Based on a price of 1,744 euros for an aluminium alloy as per LME [3], the capital tie-up within an enterprise for a rejected material amount of 122 t or 170 t is 211,931 euros or, respectively, 296,704 euros per year.

## Time as a cost factor

The time required for sampling and analysis does not automatically have a 1:1 effect on the duration of the production process. The decisive question is whether it is necessary or not in production to wait for the result of the analysis. It is mostly unavoidable within the process, however, especially at the melting furnace or at those locations where alloying is carried out, to wait for approval/release for the next process step. Depending on how long that wait is, time is a more or less critical factor in the production process that ultimately has an influence on the capacity.

### Calculation:

**Case 1:** Where it is necessary in the casting process to wait at least once per batch for approval/release based on the analysis, then process control using LIPS technology offers a clear time advantage. The measurement takes place in real-time mode and the result is immediately available. The elimination of the waiting time in this case leads to a capacity increase of 3.4 %.

**Case 2:** Where, on the other hand, the casting process is organized so that it is necessary to wait for a second analysis only if samples or measurements do not conform to requirements, then the time lost depends on the frequency of such non-conforming sam-

ples or measurements. Assuming this occurs once a day on average, the time delay per day – based on the data in Table 1 – is 13.5 min.

Assuming that 75 % of this waiting time can actually be used to speed up the production process, then the capacity increase is still around 0.7 %. The number of hours thus accumulated per year is 38 (3-shift operation) or 53.2 (4-shift operation). A cost-related evaluation of the time saving is based on an increased output and simultaneous reduction of the production costs per ton. For the sake of simplicity, the present calculation uses an all-inclusive amount of 200 euros per ton (cost difference between input and output). As can be seen in Table 5, the time saving as a result of using LIPS-based inline process control can also yield foundries monetary savings of 22,781 euros for 3-shift operation and 31,894 euros for 4-shift operation.

Item	Basis	Description	3-shift operation	4-shift operation
<b>Time as a cost factor</b>	13.5	Waiting time in minutes/ day		
	75%	Utilization of the time saving		
	0.7%	Capacity increase		
	€ 200	Input/ output cost difference		
	15 t	Furnace capacity in tons		
		Cost reduction per year	<b>€ 22,781</b>	<b>€ 31,894</b>

**Table 5: Impact of time on performance**

The fact that it is possible to conduct measurements at any time and as often as required permits 100 % monitoring of the product and production. It is hence possible, for example, to monitor an alloying modification involving one or several elements at the same time without any additional personnel and laboratory costs.

## ECONOMIC APPRAISAL

To calculate the economic efficiency, it is normally necessary to take account of all relevant factors, both quantitative and qualitative. In the preceding sections of the present article, however, only the quantitative influencing factors have been described. The qualitative factors have not been considered in this appraisal as they are not directly expressible in figures.

Nevertheless, the qualitative factors are just as important as the quantitative ones for reaching decisions, because they mostly represent the additional benefit to which a user attaches importance. Listed in the following are a few examples of qualitative factors afforded by LIPS-based inline process control:

- Automation of measurement: not dependent on personnel,
- Analysis: not dependent on laboratory operating hours,
- Improvement in the standard of quality and service for the customer,
- Reduction of the analytical uncertainty caused by sampling and solidification,
- Demonstrable 100 % control: quality and marketing advantage and, hence, better image –comprehensibility of the process,
- Optimization of the melting and casting process,
- Greater on-the-job safety through a minimum of sampling,
- Reduction in environmental pollution,
- Competitive advantage over other enterprises.

### Case study

The previous remarks are summarized in a case study. The findings are presented with the aid of a fictitious enterprise in the form of an efficiency and payback period calculation. The fictitious enterprise is a company in the secondary aluminium field that operates a foundry with a 15 t melting furnace including holding furnace and launder. The melts are produced and cast at five-hourly intervals in 4-shift operation, 315 days a year. This results in a production capacity of 22,680 t/a. The figures (rejected material, time factor, etc.) from the previous sections are also used.

To optimize the process flow in the foundry and, at the same time, achieve cost savings, there are plans to invest in an inline process control system based on LIPS technology. The persons responsible are convinced of the technical merits offered by the LIPS system and wish to elicit the impact of such an investment on performance, i.e. find out how quickly the investment would pay for itself.

As can be seen from Table 6, the company is able, as early as the first year, to make considerable cost savings by using the LIPS system and improve profitability by reducing the rejection rate and boosting output, while maintaining a constant capacity.

Item	Basis	Description	4-shift regime
<b>QUALITY CONTROL</b>			
		Reduction of analysis costs	€ 14,175
		Reduction of personnel costs	€ 29,117
		<hr/> Total, direct costs	<hr/> € 43,292
		+ overhead rate (in %)	40%
		<b>Cost reduction per year</b>	<b>€ 60,609</b>
		<i>acc. to full absorption method</i>	
<hr/>			
<b>REMELTING COSTS</b>			
	0.75%	Rejected material amount in the foundry	
	€ 200	Input/ output cost difference	
	1.25	Overall factor	
	15 t	Furnace capacity in tons	
		<hr/>	<hr/>
		<b>Cost reduction per year</b>	<b>€ 42,525</b>
<hr/>			
<b>TIME AS A COST FACTOR</b>			
	13.5	Waiting time	
	75%	Utilization of the time saving	
	0.7%	Capacity increase in %	
	€ 200	Input/ output cost difference	
	15 t	Furnace capacity in tons	
		<hr/>	<hr/>
		<b>Cost reduction per year</b>	<b>€ 31,894</b>
<hr/>			
		<b>Total impact per year on performance</b>	<b>€ 135,028</b>

Table 6: Impact of the process control investment on performance

The stated analysis and personnel costs are based on direct costing, i.e. the overheads are not taken into account in the previous section. The overheads are derived on the basis of a cautious cost estimate for a foundry-run laboratory. In addition to the general costs incurred for rent, administration, energy, etc., this example includes interest and depreciation (capital allowance) for infrastructure amounting to a total of 25,000 euros per year. Based on an average annual number of 6,480 samples, this means an overhead rate of around 40 %. The overhead rate, which varies according to laboratory size and equipment, is added to the direct costs. In concrete terms this means a quality control cost saving of 60,609 euros.

## PAYBACK CONSIDERATIONS

Those making the decisions must know within what period of time the investment expenditure can be repaid through savings and improved profits. This time span is referred to as the amortization period. From a corporate viewpoint it may amount to no more than three years, and from a realistic viewpoint it should last no more than two years. Table 7 gives a detailed list of the amortization items for this example.

Item	Basis	Description	4-shift operation	Amortization
<b>INVESTMENT COSTS</b>				
		<b>Quantalizer procurement costs</b>	<b>€ 148,000</b>	
<b>QUALITY CONTROL SAVINGS</b>				
<b>Analysis costs</b>		Reduction of analysis costs	€ 14,175	
<b>Personnel costs</b>		Reduction of personnel costs	€ 29,117	
		Total, direct costs	€ 43,292	
		+ overhead rate (in %)	40%	
		<b>Cost reduction per year</b> acc. to full absorption method	<b>€ 60,609</b>	
<b>COST REDUCTION THROUGH DECREASE OF REJECTION RATE</b>				
	0.75%	Rejected material amount in the foundry		
	€ 200	Input/ output cost difference		
	1.25	Overall factor		
	15 t	Furnace capacity in tons		
		<b>Cost reduction per year</b>	<b>€ 42,525</b>	
<b>COST REDUCTION THROUGH TIME SAVINGS</b>				
	13.5	Waiting time in minutes per day		
	75%	Utilization of time savings		
	0.7%	Capacity increase		
	€ 200	Input/ output cost difference		
	15 t	Furnace capacity in tons		
		<b>Cost reduction per year</b>	<b>€ 31,894</b>	
		<b>Sum of the yearly savings</b>	<b>€ 135,028</b>	
		<b>- sum of the costs per year</b>	<b>€ 7,500</b>	
		<b>Total amortization period</b>	<b>€ 127,528</b>	<b>1.2 years</b>

Table 7: Payback calculation

The cost of procuring a LIPS inline process control system serves as the basis for the amortization calculation. Taking the Quantalizer CLM400 manufactured by Innsitec Laser Technologies as an example, the investment costs of such a system average 148,000 euros, depending on the requirements. Added to this are annual costs of 4-shift operation (electricity, gas), servicing and maintenance, as well as spare parts, amounting to 7,500 euros. This contrasts with cost savings and improved profits from the efficiency calculation amounting to a total of 135,028 euros per year.

To calculate the amortization period, the current costs per year are deducted from the sum of the annual savings. The sum of this is set against the procurement costs. The amortization period when procuring a LIPS system for continuous process control is thus 1.2 years.

The matter is a straightforward one for the company in the case study. Given an impact on performance of 135,028 euros and an amortization period of just over a year, there is nothing more to stand in the way of procuring a LIPS inline process control system.

## CONCLUDING REMARKS

Deriving the complete cost of in-process quality control is the main aspect in this article. Correctly identifying the costs and creating awareness for the savings potential are an important precondition for any objective appraisal of the topic of process control and the investments needed for the purpose.

As experts repeatedly confirm, 100 % monitoring is impracticable with currently available control and analysis possibilities. There are however increasing calls, especially from auto makers, to keep precise records for every casting, batch or product for the purpose of traceability. To the authors' knowledge, no enterprise to date, it must be said, has kept complete documentation including chemical analysis data.

Inline process control using LIPS technology makes it possible to analyze molten metal in real-time mode, something which conventional methods such as the spark-OES technique are unable to do. Process capability (to DIN ISO 21747) in the foundry can consequently be increased by means of the LIPS technology: in the short term by the foundry workers having direct feedback concerning the melting and casting process and being able to respond immediately if alloying measures exceed or fall below limits and, in the longer term, by being able to derive concrete process optimization models from the measurements and experience gained with inline process control.

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