Journal of Engineering and Applied Sciences 2 (12): 1735-1742, 2007
ISSN: 1816-949X

Evolutionary Programming to Improve Yield and Overall Equipment Effectiveness of Casting Industry

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Abstract: In this modern manufacturing era, the production has become unimaginably sophisticated. The world class manufacturing is possible with CNC machines, robots and even unmanned factory will become real. But the productivity is improved not only by automated operations but there should not be any wastage (losses) by any means. Total Productive Maintenance (TPM) is an innovative Japanese concept to minimize the manufacturing losses and it has been proven as a successful technique used for corrective, preventive and predictive maintenance policies in many manufacturing industries. Overall Equipment Effectiveness (OEE) is the metric for TPM implementation. OEE attempts in identifying the production losses, expressed in terms of three factors, namely availability, performance and quality. Due to different applications and other varying circumstances like the type of industry, production system, process and machine type, some inconsistencies in the calculation of OEE have been encountered. Its definition also differed with respect to the applications and authors. In this study, it is proposed to introduce a new term “yield” in the OEE calculation. The proposed model has been analyzed with a case study in a casting industry. For any industry the main objective is to improve the performance of its processes, equipments etc. To achieve it, the parameters of the processes or equipment should be optimized. In this case analysis, Evolutionary Programming is used for optimizing the parameters to improve OEE.

Key words: Total productive maintenance, overall equipment effectiveness, yield, casting

INTRODUCTION

Keeping ahead of the game is tougher than ever in today’s manufacturing industry. Competition is worldwide and markets are fast becoming price sensitive. These challenges are forcing companies to implement various productivity improvement efforts to meet the needs of ever changing market demand. The Total Productive Maintenance (TPM) paradigm, launched by Nakajima in the 1980’s, has provided a quantitative metric for measuring the productivity of an individual production component. Though OEE is a part of TPM, it has been used extensively outside the maintenance paradigm (Kanthi *et al*., 2006). OEE has been used extensively for equipment productivity improvement. OEE was recognized as a fundamental method for measuring equipment performance beginning the late 1980s and early 1990s. Now it is accepted by management consultants as a primary performance metric. The OEE measure attempts to reveal the hidden costs associated with a piece of equipment. When it is applied by autonomous small groups on the shop-floor together with quality control tools, OEE is an important complement to the traditional top-down oriented performance measurement systems. OEE is often used as a driver for improving performance of the business by focusing on quality, productivity and equipment availability issues and hence aimed at reducing non-value adding activities often inherent in manufacturing processes.

Problem background: In considering OEE, Nakajima (1988) defines 6 big equipment losses.

- Equipment failure/breakdown are categorized as time losses when productivity is reduced and quality losses caused by defective products.
- Setup/adjustment time losses result from downtime and defective products that occur when the production of one item ends and the equipment is adjusted to meet the requirement of another item.

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- Idling and minor stop losses occur when production is interrupted by a temporary malfunction or when a machine is idling.
- Reduced speed losses refer to the difference between the equipment design speed and the actual operating speed.
- Reduced yield occurs during the early stage of production from machine startup stabilization.
- Quality defects and rework are losses in quality caused by malfunctioning of production equipment.

The first two losses are known as downtime losses and are used to calculate the availability, A of a machine. The 3rd and 4th losses are speed losses, which determine the so called performance efficiency, P of a machine by the losses that occur as a consequence of operating at less than the optimum conditions. The final two losses are considered to be losses due to defects, the larger the number of defects, the lower the quality rate, Q of parts within the factory. OEE is measured as OEE = Availability * Performance * Quality.

Six big losses is reviewed through Raouf (1994), De Groote (1995), Tom (1997), Kannan (2001), Philip (2002) and Bamber *et al*. (2003). Previous research has targeted various aspects of OEE for example, Ljundberg (1998) states that the definition of OEE does not take into account all factors that reduce the capacity utilizations, e.g. planned downtime, lack of material input, lack of labour.

Patrik and Magnus (1999) insists the use of OEE in combination with an open and decentralized organization design. Ki-Young *et al*. (2001) pointed out that the original definition of OEE suggested by Nakajima (1998) is not appropriate for capital intensive industry and he believe that loss classification schemes are ultimately tied to the industry type. Samuel *et al*. (2003), Nachiappan (2006) and Kanthi (2006), expressed the importance of the quantitative OEE analysis for the whole factory. Sarkar (2007) states how six sigma methodology has been applied for process improvement considering OEE as a parameter. Stefan (2003) pointed out that in OEE calculation it is assumed that there is a fixed ideal cycle time for each machine, but practically it is not so. Ron (2006) indicates the imperfection in applying OEE for the stand alone equipment. Muchiri (2007) discussed the difference between the OEE theory and its practical applications in industries.

Although OEE is accepted as an effective measure of manufacturing performance and as a driver of performance improvements, reported applications of this approach suggest there are inconsistencies in how it is calculated and consequently, what figures are representative of an optimum performance and how OEE measurement can influence performance improvement. In the literature, owing to different definitions and applications of OEE as well as other varying circumstances in different factors such as industry, production system, process and machine type, some inconsistencies in the calculation of OEE have been encountered.

Problem definition: Overall Equipment Effectiveness (OEE) is calculated simply the multiplication of availability, performance, quality. In this OEE calculation the six big losses are taken in to account and these losses are considered in terms of time, No. of units etc. The exact definition of OEE differs between applications and authors. Nakajima (1988) was the first author of OEE and Groote (1995) is one of the several later authors. When assessing OEE, it is not necessarily important that Nakajimma's 6 big losses are used explicitly or definitely. However it is necessary to develop an organizations own classification frame work for the losses. On this basis, the authors of this paper analyzed and introduce. One more magazing contributing parameter for the OEE calculation for a casting process.

OEE in casting process: In casting industry the metal is melted in the furnace but after solidification all the molten metal is not converted into product. Some are wasted in gating and runner riser provisions. That is why, even though the weight of molten metal is more, the weight of products coming out of casting process is very less. This wastage is termed as returns.

When the product is scrapped (in the form of returns) it does not just consume available processing time and cost. But also consumed some raw materials. These characteristics of process are not taken in to account by OEE measurement though they may have more significant impact on the organization than the issue around the OEE calculation. In these circumstances, OEE need to be augmented with other characteristics relating to process waste in order for it to be a useful performance, measure for manufacturing systems. From the literature it is clear that the OEE analysis can be used in a different way depending upon the type of industry or process. In casting process, yield plays an important role in assessing the overall performance of the firm. If the effectiveness of the casting process is analyzed without considering the yield it will mislead the management that the material utilization is good and there is no need for further improvement in the process. So, the authors introduced the term yield in the OEE calculations of a casting industry.

$$\text{Yield} = \frac{\text{Casting weight}}{\text{Pouring weight}}$$

Where,
Casting weight = Pouring weight-returns

Case study: A case study is carried out in a casting industry. The company manufactures plummer block, pipe fittings, couplings and flanges of grey cast iron.

A dedicated work force of 200 employees in production and testing. The company has modern laboratory facilities to check the defects and compositions of castings.

System description: The manufacturing system under consideration consists of machines mixing Muller with a capacity of 500 kg, automated moulding machine, conveyors and induction furnaces, Jolting and squeezing machines, knockout, shot blasting machine and cleaning machines. The plant lay out of the manufacturing system in show in Fig. 1. They manufacture plummer block, pipe fittings, couplings and flanges of gray cast iron.

Optimization is done for the product size wise, by considering the, molding process. The major losses are identified in molding processes. So, the analysis of optimization is focused only on casting process.

Existing OEE: Data were collected for the couplings of various sizes like 2.0, 2.5, 3, 4 and 6 inch. For our analyses, 3 inch coupling and 6 inch coupling are taken into consideration.

The following definitions are used for calculating over all equipment effectiveness.

- Operating Time (OT).
- Production Weight (PW).
- Rejection Weight (RW).
- Actual Number of Boxes (NB).
- Number of Patterns (NP).
- Casting Weight (CW).
- Pouring Weight (POW).

Operating Time (OT): Operating time is the total working time of a machine within a shift (8 h) excluding the downtime such as equipment failures, shortage in mould preparation.

Production Weight (PW): It is the final weight of a product after the solidification of a molten metal in the cavity in a particular shift.

Rejection Weight (RW): It is the total weight of product which in the boxes is rejected as scrap or waste due to casting defects like blow holes, damaged edges, etc.

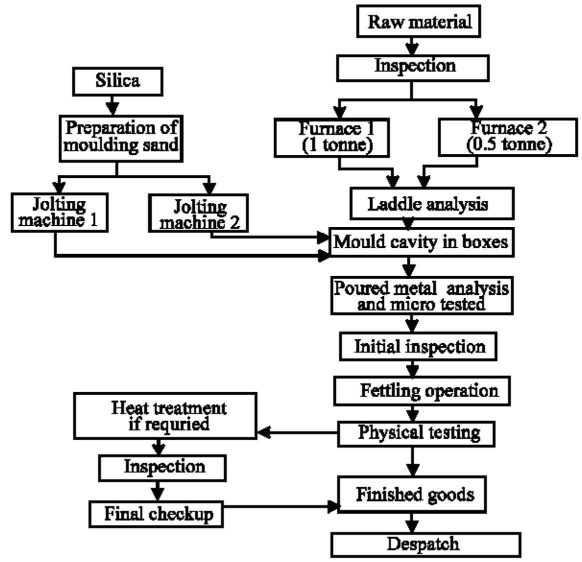

Fig. 1: Plant layout

Actual Number of Boxes (NB): It is a term which reveals the total number of boxes produced within a shift of 8 h.

Number of Pattern (NP): It is a numerical value that indicates no of patterns in a particular box. It is constant for a particular size product.

Casting Weight (CW): It is the weight of the single product casted.

Pouring Weight (POW): It is the weight of the molten metal taken from the furnace for the purpose of casting a particular size of product.

OEE calculation for 3 inch coupling:

Total available time	=	8 h = 480 min
Planned down time	=	30 min
Loading time	=	Total available time-planned down time
	=	480-30 = 450 min
Unplanned down time	=	35 min
No. of boxes	=	400
Production weight	=	2989 kg
Rejection weight	=	336 kg
No. of patterns	=	12
Casting weight	=	0.54 kg (540 g)
Pouring weight	=	10 kg (10000 g)

$$\text{Availability (A)} = \frac{\text{Actual operating time}}{\text{Planned production time}}$$

$$= \frac{450\text{-}35}{450} = \frac{415}{450} = 0.92$$

$$\text{Performance (P)} = \frac{\text{Actual production in boxes/operating time}}{\text{Standard production in boxes /planned production time}}$$

$$= \frac{450/415}{435/450} = \frac{0.964}{0.978} = 0.99$$

$$\text{Quality (Q)} = \frac{\text{Production weight-rejection weight}}{\text{Production weight}}$$

$$= \frac{2989\text{-}336}{2989} = \frac{2653}{1754.8} = 0.88$$

$$\text{OEE} = A * P * Q = 0.807$$

The existing OEE values for 3 inch and 6 inch coupling is shown in Table 1 and 2, respectively.

OEE calculation by the proposed methodology for 3 inch coupling: In the OEE calculation of casting industry the term yield is introduced.
Therefore,

$$\text{OEE} = \text{Availability}\times\text{Performance}\times\text{Quality}\times\text{Yield}$$

In this case, weight of the individual casting = 0.54 Kg. Number of patterns = 12

$$\text{Yield} = \frac{\text{Casting weight}}{\text{Pouring weigh}}$$

$$= \frac{(0.54\times12)}{10} = 0.648$$

Therefore,

$$\text{OEE} = 0.922\times0.986\times0.888\times0.648 = 0.523$$

Similarly, the yield for 6 inch coupling and the proposed OEE is also calculated and the values are tabulated in Table 3 and 4.

Comparison between the existing OEE and the proposed OEE for 3 inch coupling and 6 inch coupling is tabulated in Table 5 and 6, respectively. Comparison Graph is also drawn in Fig. 2 and 3.

From the comparison chart it is clear that the value of OEE is decreases because of the introduction of the term yield in the OEE calculation. This shows the impact of yield in the OEE calculation of casting industry. If the

Table 1: Existing OEE for 3.00 inch coupling

Availability	Performa	Quality	OEE
0.811	0.939	0.887	0.675
0.878	0.999	0.884	0.775
0.893	0.995	0.885	0.787
0.907	0.993	0.886	0.798
0.922	0.966	0.888	0.807
0.933	0.998	0.916	0.853
0.933	0.796	0.937	0.696
0.933	0.901	0.929	0.781
0.944	0.987	0.840	0.783
0.922	0.991	0.944	0.862

Table 2: Existing OEE for 6.00 inch coupling

Availability	Performa	Quality	OEE
0.999	0.761	0.851	0.648
0.949	0.798	0.866	0.655
0.898	0.835	0.865	0.649
0.849	0.878	0.880	0.656
0.800	0.926	0.913	0.676
0.816	0.925	0.897	0.677
0.831	0.924	0.894	0.687
0.847	0.926	0.875	0.686
0.862	0.925	0.836	0.667
0.878	0.924	0.817	0.663

Table 3: OEE for 3.00 inch coupling from the proposed methodology

Availability	Performa	Quality	Yield	OEE
0.811	0.939	0.887	0.648	0.437
0.878	0.999	0.884	0.648	0.502
0.893	0.995	0.885	0.648	0.510
0.907	0.993	0.886	0.648	0.517
0.922	0.966	0.888	0.648	0.523
0.933	0.998	0.916	0.648	0.553
0.933	0.796	0.937	0.648	0.451
0.933	0.901	0.929	0.648	0.506
0.944	0.987	0.840	0.648	0.507
0.922	0.991	0.944	0.648	0.559

Table 4: OEE for 6.00 inch coupling from the proposed methodology

Availability	Performa	Quality	Yield	OEE
0.999	0.761	0.851	0.576	0.373
0.949	0.798	0.866	0.576	0.377
0.898	0.835	0.865	0.576	0.374
0.849	0.878	0.880	0.576	0.378
0.800	0.926	0.913	0.576	0.390
0.816	0.925	0.897	0.576	0.390
0.831	0.924	0.894	0.576	0.396
0.847	0.926	0.875	0.576	0.395
0.862	0.925	0.836	0.576	0.384
0.878	0.924	0.817	0.576	0.382

Table 5: Comparison between existing and proposed OEE values for 3 inch coupling

Existing OEE	OEE in proposed model
0.675	0.437
0.775	0.502
0.787	0.510
0.798	0.517
0.807	0.523
0.853	0.553
0.696	0.451
0.781	0.506
0.783	0.507
0.862	0.559

Table 6: Comparison between existing and proposed OEE values for 6 inch coupling

Existing OEE	OEE in proposed model
0.648	0.373
0.655	0.377
0.649	0.374
0.656	0.378
0.676	0.390
0.677	0.390
0.687	0.396
0.686	0.395
0.667	0.384
0.663	0.382

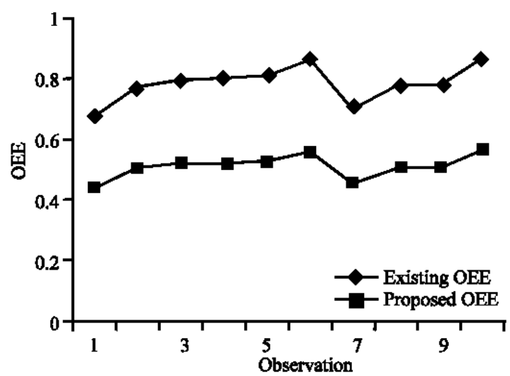

Fig. 2: Comparison of OEE for 3 inch coupling

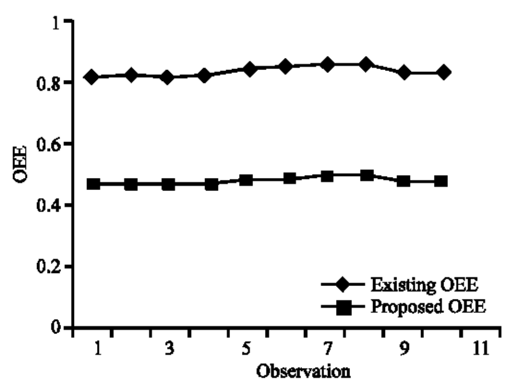

Fig. 3: Comparison of OEE for 6 inch coupling

effectiveness of the casting process is analyzed without considering the yield it will mislead the management that the material utilization is good and there is no need for further improvement in the process. The OEE calculation with yield will give the exact picture to the management about the process.

The OEE value is an important performance alarm for all the industries. So, if the OEE value decreases, definitely the management will focus their attention to improve it. One among the method to improve the OEE value is to optimize the parameters of OEE. Now a days optimization problem have attracted great attention in the industrial domain. For optimization, Evolutionary Programming method is used. It is a powerful optimization procedure that has been successfully applied to a number of optimization problems is capable of determining the global or nearer global solutions.

Evolutionary programming: Evolutionary Programming, originally conceived by Lawrence J. Fogel in 1960, is a stochastic optimization strategy similar to Genetic Algorithms but instead places emphasis on the behavioral linkage between parents and their offspring, rather than seeking to emulate specific Genetic Operators as observed in nature. Evolutionary Programming is similar to Evolution Strategies, in that normally distributed mutations are performed in both algorithms. It has been recently applied successfully to many numerical and combinational optimization problems (Xin, 1999; Tan, 2003). Optimization by EP can be summarized below

- Choose an initial population of trial solutions at random. The number of solutions in a population is highly relevant to the speed of optimization, but no definite answers are available as to how many solutions are appropriate (other than >1) and how many solutions are just wasteful.
- Each solution is replicated into a new population. Each of these offspring solutions are mutated according to a distribution of mutation types, ranging from minor to extreme. The severity of mutation is judged on the basis of the functional change imposed on the parents.
- Each offspring solution is assessed by computing its fitness. Typically, a stochastic tournament is held to determine "N" solutions to be retained for the population of solutions, although this is occasionally performed deterministically. There is no requirement that the population size is to be held constant, however, not that only a single offspring be generated from each parent.

Proposed evolutionary programming algorithm:

Step 1 : Identify the controllable parameters.
Step 2 : Define the objective function.
Step 3 : Initialize the variables (Random generation).
Step 4 : Apply OEE function to all parent values.
Step 5 : Mutate (or) create childs by using Gaussian random variables.
Step 6 : Apply OEE function to all child values.
Step 7 : Sort list the high OEE values.
Step 8 : Assign these values as parent for next iteration.
Step 9 : Again iterate until optimized values are attained.

The following controllable parameters are identified for OEE calculation in casting industry.

- Operating Time (OT).
- Production Weight (PW).
- Rejection Weight (RW).
- Actual Number of Boxes (NB).
- Number of Patterns (NP).
- Casting Weight (CW).
- Pouring Weight (POW).

The objective function is defined as

$$\text{Max (OEE)} = \text{Max } (A * P * Q * Y)$$

$$= \text{Max } \left(\frac{OT}{450} * \frac{NB/OT}{(SNB/PPT)} * \frac{PW\text{-}RW}{PW} * \frac{CW}{POW}\right)$$

From the data collected, the lower limit and upper limit of the parameters are fixed. Random numbers are generated within the limit mentioned above. The OEE function is applied to all parent values. By using Gaussian random variables childs are created. Then the OEE function is applied to all child values. The OEE values are sort listed. These values are assigned as parent for next generation. Similarly the iteration is continued until optimized values are attained.

Steps to obtain optimized OEE for 3 inch coupling of the case study industry:

Step 1 : Initially controllable parameters are randomly generated.
Step 2 : By using objective function OEE is calculated. One sample value is shown in Table 7.
Step 3 : Gaussian random numbers are generated.
Step 4 : By adding gaussian random numbers to each parent values childs are created.
Step 5 : OEE function is applied to each child values. The Child values before sorting with yield are shown in Table 8.
Step 6 : After sorting, child values are created.
Step 7 : OEE is calculated for this child values and the values are shown in Table 9.
Step 8 : The above child values act as a parent to next child values.
Step 9 : Similarly the iteration is continued until optimized values are obtained. The optimized values are shown in Table 10.

Table 7: Parent values

Operation time in minutes	No of boxes moulded	Production weight in kg	Rejection weight in kg	Casting weight in grams	Pouring weight in grams	OEE
405.34	427.72	3113.5	286.01	564.37	10155	0.56016

Table 8: Child values (before sorting)

Operation time in minutes	No of boxes moulded	Production weight in kg	Rejection weight in kg	Casting weight in grams	Pouring weight in grams	Yield	OEE
425.11	394.72	2666.3	160.53	568.25	10100	0.78768	0.73183
378.84	410.13	2837.5	369.54	540.56	10341	0.66408	0.5933
405.32	427.7	3113.5	285.98	564.34	10155	0.778	0.68678
397.91	408.26	2638.6	426.98	555.13	10275	0.75642	0.58828
422.47	349.5	2715.1	292.13	568.94	10079	0.79024	0.56016
410.78	369.65	2748.9	555.14	274.46	10349	0.75098	0.56792
396.49	429.33	2750.6	402.51	565.39	10193	0.77654	0.64682
366.05	423.21	2985.8	305.23	552.8	10430	0.74202	0.64075
414.34	370.13	2789.9	211.82	549.19	10427	0.73739	0.5732
395.19	424.34	2750	351.43	549.2	10300	0.74646	0.6279

Table 9: Child values (after sorting)

Operation time in minutes	No of boxes moulded	Production weight in kg	Rejection weight in kg	Casting weight in grams	Pouring weight in grams	Yield	OEE
422.47	349.5	2715.1	292.13	568.94	10079	0.56016	0.78777
410.78	369.65	2748.9	274.46	555.14	10349	0.57081	0.7319
414.3	370.09	2789.9	211.78	549.15	10427	0.58035	0.77804
397.92	408.27	2638.6	426.99	555.15	10275	0.58831	0.75643
378.79	410.07	2837.5	369.49	540.51	10341	0.59573	0.79031
395.19	424.34	2750	351.43	549.2	10300	0.6279	0.75099
396.52	429.36	2750.6	402.54	565.42	10193	0.64689	0.77667
366.11	423.27	2985.8	305.29	552.86	10430	0.64919	0.74222
425.14	394.75	2666.3	160.56	568.27	10100	0.66415	0.7374
405.34	427.72	3113.5	286.01	564.37	10155	0.68685	0.74654

Table 10: Optimized values

Operation time in minutes	No of boxes moulded	Production weight in kg	Rejection weight in kg	Casting weight in grams	Pouring weight in grams	OEE
405.53	427.91	3113.7	286.19	564.55	10155	0.68731

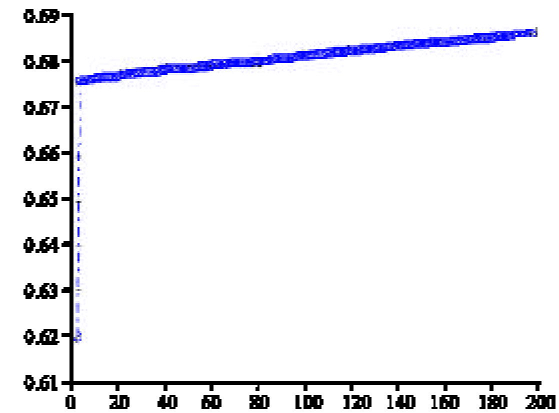

Fig. 4: Optimized OEE

Table 11: Summary of OEE results for 3 inch coupling

Existing OEE (without considering yield)	OEE value (By considering yield)	Optimized OEE value
0.807	0.523	0.687

The optimized OEE values for 3 inch coupling is shown in Fig. 4.

The optimized parameters are shown in Table 10. The optimized values of OEE parameter are suggested to the Industry.

Thus the impact of yield in the calculation of OEE in casting industry is analyzed and it is suggested to the case study industry to run the process with the optimum conditions. The summary of the OEE results for 3 inch coupling of the case study industry is tabulated in Table 11.

CONCLUSION

The exact definition of OEE differs between applications and authors. OEE calculation does not take into account all factors that reduce the capacity utilization, lack of material input etc. However, it is necessary to develop an organizations own classification frame work for the losses in the OEE calculation. In casting industry the metal is melted in the furnace but after solidification all the molten metal is not converted into product. In this process, yield plays an important role in assessing the overall performance of the firm. So, it is proposed to introduce a new term "yield" in the OEE calculation of a casting industry. A case study has been carried out in a casting industry and the OEE is calculated with yield as one among the parameter. The results shows the way for the management towards the improvement process. For any industry the main objective is to improve the performance of its processes, equipments etc. To achieve it the parameters of the processes or equipment should be optimized. The OEE parameters are optimized using Evolutionary Programming (EP) using MATLAB. Thus the impact of yield in the calculation of OEE in casting industry is analyzed and it is suggested to the practicing industry to run the process with the given optimum conditions.

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