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Reduction Of Casting Defects Using Taguchi Method

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Abstract: *This paper aims at the reduction of casting defects of a plate cylinder which is used in an offset printing machine to transfer ink from the inking unit. Four variables are considered which directly affect the casting of the cylinder. Taguchi method was selected for the optimization of these selected four parameters. Taguchi method is based on performing evaluation or experiments to test the sensitivity of a set of response variables to a set of control parameters (or independent variables) by considering experiments in "orthogonal array" with an aim to attain the optimum setting of the control parameters. Four control parameters were used to reduce the defects that occur on the plate cylinder.Moisture Content, green strength, sand particle size and mould hardness were selected as the control parameters. The analysis showed a reduction in the number of defects when optimum input factor values were selected.*
Keywords: *Green strength, mould, orthogonal, taguchi*

I. Introduction

Metal casting process begins by creating a mold, which is the negative shape of the part required for manufacturing. The mold is made from a refractory material, for example, sand. The metal is heated in an oven until it melts, and the molten metal is poured into the mould cavity. The liquid takes the shape of cavity, which is the shape of the part. It is cooled until it solidifies. Finally, the solidified metal part is removed from the mould. A large number of metal components are made by casting. One of the most important metal casting method is the sand casting method.A casting defect is an irregularity in the metal casting process that is undesired. Some defects can be tolerated while others can be repaired, otherwise they must be eliminated. They are broken down into mainly into five categories viz gas porosity, shrinkage defects, mold material defects, pouring metal defects, and metallurgical defects. The removal of all the casting defects from a casting process is not possible as there are a number of factors affecting it but the optimization of the control parameters can lead us to achieve better results. This paper tries to reduce the defects in a casting process by optimizing its control parameters.

II. Objectives

The paper aims at finding a method and using it which can be applied in industry to reduce the defects that occur during casting process. The optimization is done with the help of taguchi method and usind MINITAB software.

The objectives of this paper is to

- Reduce the defects in the casting process of a plate cylinder by optimizing the control factors.
- Use taguchi method for optimizing the factors and find its effectiveness.
- Find the reduced defect count with the help of softwares.

III. Literature Review

A detailed literature review was done on studying about the common casting defects, the ways of reducing it and the software packages used for optimizingthe factors.

R. B. Heddure et alputs forward that the casting defects can be minimized by taking corrective actions in the tools like pattern, mould making, core making and melting process. The paper presents a systematic procedure to identify as well as to analyze major casting defects. Defects are responsible for time waste, money and eventually they affect productivity adversely. The defects need to be diagnosed correctly for appropriate remedial measures; otherwise new defect may get introduced. The proper classification and identification of particular defect is basic need to correct and control quality of casting. Keeping rejection to a bare minimum is essential to improve the yield and increase the effective capacity of the foundry unit and also improve the productivity. This paper identifies two major defects slag and porosity. There are many reasons to generate these defects. So it preferably necessary to reduce it as much as possible by appropriate analysis of the defects which includes the root cause analysis so that actual reasons behind occurring the defects can be find out to make the corrective action. In this paper use six sigma technique and Shainin tool for identify and analysis casting defect. Shainin tool works on elimination principle. Final result of this work has to be reducing slag and porosity defect by taking corrective action. Tool should be identifying the sources of variation clearly. [1]

Saurabh Gupta et al focus on minimizing the defects in Al-Mg alloy castings in green sand casting process by optimizing the casting process parameters. Several process parameters contribute to these casting defects. Literature review reveals that moisture content, binder percentage and pouring temperature are among the most influencing parameters which contribute to the casting defects like sand drop, blow holes, scabs, and pinholes. In this paper these three process parameters are optimized by using the Taguchi's design of experiment method. The Taguchi approach is used to capture the effect of signal-to-noise ratios of the experiments based on the orthogonal array. Robust design factor values were estimated from the signal-to-noise calculations**.** [2]

Uday A. Dabade et al combined and used the design of experiments and computer assisted casting simulation techniques to analyze the sand related and method related defects in green sand casting. An attempt has been made to obtain the optimal settings of the moulding sand and mould related process parameters of green sand casting process of the selected ductile iron cast component. The green sand related process parameters considered are, moisture content, green compression strength, and permeability of moulding sand and mould hardness (in horizontal direction). In first part of this paper Taguchi based L18 orthogonal array was used for the experimental purpose and analysis was carried out using Minitab software for analysis of variance (ANOVA) and analysis of mean (AOM) plot. ANOVA results indicate that the selected process parameters significantly affect the casting defects and rejection percentage. In the second part, shrinkage porosity analysis is performed using casting simulation technique by introduction of a new gating system designed, solid model developed for four cavities mould. Number of iterations using casting simulation software was performed for mould filling and solidification analysis to reduce the level and intensities of shrinkage porosities in cast component. With new gating and feeding system design reduction in shrinkage porosity (about 15%) and improvement in yield (about 5%) is observed. [3]

Udhaya Chandran. R. M. mainly focus on to minimize the casting defects such as, sand drop, sand blow holes, scabs, pinholes. The optimization technique used for this purpose is taguchi method. The parameters considered are moisture content (%), green strength(g/cm^2), mould hardness, sand practical size (AFS).The Taguchi approach is used to capture the effect of signal to noise ratio of the experiments based on the orthogonal array used due to optimum conditions are found. The outcome of this paper is that the selected process parameters continuously affect the casting defects in foundry. The improvement expected in reduction of casting defects is found to be 47.66 %. [4]

B.R. Jadhav et al puts forward in their paper that it is almost impossible to produce defect free castings. Occurrence of the defect may involve single or multiple causes. These causes can be minimized through systematic procedure. The paper represents a procedure to analyze and minimize casting defect, cold shut in automobile cylinder block of grey cast iron Grade FG150. The paper finds that gaiting systems are not always responsible for the defect occurrence and the defect reduction by controlling alloy composition and pouring temperature is done. The seven quality control methodology is used to analyze and reduce defects which includes check sheet, pareto analysis, cause effect diagram, flow chart, scatter diagram, histogram and control chart. [5]

IV. Offset Printing

It is a printing process used since 1798.Offset or as the name suggests, originally made use of locks with areas and lines to be drawn in a greasy substance. The lines and areas had affinity for ink, while the other areas where respective to water. If the block was jetted, then inked, only the areas and linear drawn in grease retained the ink, and transferred it to paper. Figure 1 [6] shows the basic working principle of a printing machine.

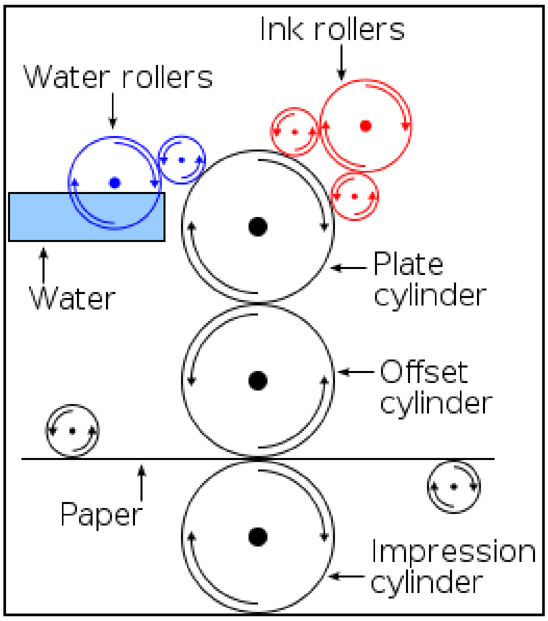

Fig 1:- Offset printing machine

The modern version of lithography makes use of the principle that the same areas of the printing plate bear the image to be printed are receptive to ink, while the other areas are blank and respective to the veneer ink. The distinctions are made by chemical or metallic coatings on the metal plate. When map image is imposed photographically on to the plate, the veneer material is altered removed only in the areas to be linked. Remaining areas are unchanged and will not be receptive to the ink. Since the veneer is thin, there is virtually no depth to the image on the plate. The image is transferred, therefore not by pressing it on to the paper. In fact, most lithographic printing is done by offset press in which the image is transferred from printing plate rubber blanket cylinder from where the paper picks up the image with suitable pressure from the impression cylinder. Offset lithography printing is the most widely used process in the commercial printing industry. Its major application is printing on the paper, thus it is ideal for printing newspaper, books, magazines and all other paper publications.

There are three main cylinders in an offset lithographic printing unit:-

- Plate cylinder.
- Blanket cylinder
- Impression cylinder

The plate cylinders are positioned in such a way that it can quickly and accurately locate the printing plate, by means of front and rear clamps which grip two ends of the plates and provide tension around the cylinder. Offset or blanket cylinders are manufactured with considerable care and at first sight appear to be an exclusive item. Many printers engaged is general printing use blankets in the medium range of hardness for all purpose quite successfully.During the run of most jobs, the blanket will be cleaned periodically, and this should be carried out in a mechanized manner. As there is almost certainly will be an accumulation of flat form the paper on blanket of coating form such stoke. This must be removed by first washing the blanket with a swab soaked in water, and then followed by a through washing with swab soaked in a good quality blanket wash the procedure must to wash an area and immediately dry it with another swab. This prevents the blanket wash form evaporating too quickly and leaving behind residue of ink in a thin film. This thin film can quickly develop to form glaze over whole surface of the blanket which results in a poorly printed sheet, as the image is formed on a glazed surface instead of the rubber and is not picked up and transferred properly .The periodic cleaning of the blanket with methyl ethyl ketone will help in removing glaze, which is also caused by the natural oxidation of the rubber. The impression cylinder carries the sheet through the nip, where the ink is finally transferred under the pressure to the printing stock. This is the moment of truth where the smallest dots, the finest lines, the lightest tints and heaviest solid are laid upon the paper. The slightest variation in pressure, packing, inking, clamping will be recorded at this juncture.

In this paper the casting defects of the plate cylinder is minimized by the taguchi method.

V. Taguchi Method

Taguchi method is based on performing evaluation or experiments to test the sensitivity of a set of response variables to a set of control parameters (or independent variables) by considering experiments in orthogonal array with an aim to attain the optimum setting of the control parameters. Orthogonal arrays provide a best set of well balanced (minimum) experiments. Table 4.1 shows eighteen standard orthogonal arrays along with the number of columns at different levels for these arrays. An array name indicates the number of rows and columns it has, and also the number of levels in each of the columns. For example array $L_4(2^3)$ has four rows and three "2 level" columns. Similarly the array $L_{18}(2^1 3^7)$ has 18 rows; one "2 level" column; and seven "3 level" columns. Thus, there are eight columns in the array L_{18}. The number of rows of an orthogonal array represents the requisite number of experiments. The number of rows must be at least equal to the degrees of the freedom associated with the factors i.e. the control variables. In general, the number of degrees of freedom associated with a factor (control variable) is equal to the number of levels for that factor minus one. For example, a case study has one factor (A) with "2 levels" (A), and five factors (B, C, D, E, F) each with "3 level". Table 1 depicts the degrees of freedom calculated for this case. The number of columns of an array represents the maximum number of factors that can be studied using that array. [7]

Table 1:- Standard orthogonal arrays

Orthogonal array	Number of rows	Maximum number of factors	Maximum number of columns at these levels			
			2	3	4	5
L_4	4	3	3	-	-	-
L_8	8	7	7	-	-	-
L_9	9	4	-	4	-	-
L_{12}	12	11	11	-	-	-
L_{16}	16	15	15	-	-	-
L_{16}'	16	5	-	-	5	-
L_{18}	18	8	1	7	-	-
L_{25}	25	6	-	-	-	6
L_{27}	27	13	-	13	-	-
L_{32}	32	31	31	-	-	-
L_{32}'	32	10	1	-	9	-
L_{36}	36	23	11	12	-	-
L_{36}'	36	16	3	13	-	-
L_{50}	50	12	1	-	-	11
L_{54}	54	26	1	25	-	-
L_{64}	64	63	63	-	-	-
L_{64}'	64	21	-	-	21	-
L_{81}	81	40	-	40	-	-

5.1 Signal To Noise (S/N) Ratio

Generally, a process to be optimized has several control factors (process parameters) which directly decide the target or desired value of the output. The optimization then involves determining the best levels of the control factor so that the output is at the target value. Such a problem is called as a "STATIC PROBLEM". This can be best explained using a P-Diagram (Figure 2). "P" stands for Process or Product. The noise is shown to be present in the process but should have no effect on the output. This is the primary aim of the Taguchi experiments - to minimize the variations in output even though noise is present in the process. The process is then said to have become robust.

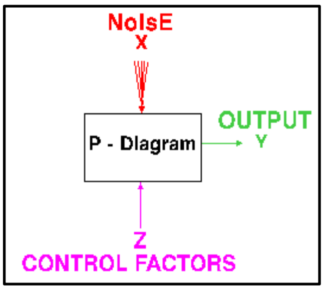

Fig 2:- P- Diagram for static problems

There are three forms of *signal to noise* (S/N) ratio that are of common interest for optimization of static problems.

5.1.1 Smaller The Better
This is expressed as
$n = -10Log_{10}$[Mean of sum of squares of measured data](1)
This is usually the chosen S/N ratio for all the undesirable characteristics like "defects" for which the ideal value is zero. When an ideal value is finite and its maximum or minimum value is defined (like the maximum purity is 100% or the maximum temperature is 92 K or the minimum time for making a telephone connection is 1 sec) then the difference between the measured data and the ideal value is expected to be as small as possible.

5.1.2 Larger The Better
This is expressed as
$n = -10Log_{10}$[Mean of sum of squares of reciprocal of measured data] (2)
This is often converted to smaller-the-better by taking the reciprocal of the measured data and next, taking the S/N ratio as in the smaller-the-better case.

5.1.3 Nominal The Best
This is expressed as

$$\mathrm{n} = -10\mathrm{Log}_{10}\left[\frac{\text{Square of mean}}{\text{Variance}}\right] \quad (3)$$

This case arises when a specified value is the most desired, meaning that neither a smaller nor a larger value is desired. From the above cases it is clear that we have to take the smaller the better approach to reduce the defects.
Steps employed for taguchi method
1) Select the design matrix and perform the experiments
2) Calculation of factor effects
3) Selecting optimum factor levels
4) Developing the additive model for factor effects
5) Analysis of Variance (ANOVA)
6) Interpretation of ANOVA table.
7) Prediction of η under optimum conditions

VI. Optimization Of Factors Levels

From detailed study the four factors which can control almost all the defects was found. These factors were called control variables as it controls the output results. The four control variables selected for obtaining optimum output were
1) Moisture Content (%)
2) Green Strength (g/cm^2)
3) Sand Particle Size (AFS)
4) Mould Hardness (Number)

The selected four factors were tested at three levels.

Table 2:- Level of the control variables

Parameters	Level 1	Level 2	Level 3
Moisture content (%)	3.2	3.8	4.3
Green Strength(g/cm^2)	1200	1400	1800
Sand Particle size(AFS)	50	52	54
Mould hardness (nu)	50	60	75

The study is associated with four factors with each at three levels. Table 1 indicates that the best suitable orthogonal array is L_9.Table 3 shows the design matrix for L_9 array for four factors A, B, C and D. Next conduct all the nine experiments and observe the surface defect counts per unit area. The arrangement of the factors in L_9 array in MINITAB software is given in Table 4.

Table 3:- L_9 array arrangement

Expt No.	Column number and factor assigned			
	1 (A)	2 (B)	3 (C)	4 (D)
1	1	1	1	1
2	1	2	2	2
3	1	3	3	3
4	2	1	2	3
5	2	2	3	1
6	2	3	1	2
7	3	1	3	2
8	3	2	1	3
9	3	3	2	1

The arrangement of the factors in arrays is represented in the table below. The software used for this purpose is the MINITAB statistical tool.

Table 4:- Arrangement of the data in L9 orthogonal array

↓	C1	C2	C3	C4
	Moisture content	Green strength	Sand particle size	Mould hardness
1	3.2	1200	50	50
2	3.2	1400	52	60
3	3.2	1800	54	75
4	3.8	1200	52	75
5	3.8	1400	54	50
6	3.8	1800	50	60
7	4.3	1200	54	60
8	4.3	1400	50	75
9	4.3	1800	52	50

For the given arrangement of the percentage rejection of parts due to defects were taken into account. Here we have to minimize the number of rejections due to defects, so “smaller the better” approach is used here. The observed rejections are shown in table 5.

Table 5:- Experimentally observed defects

Worksheet 1 **

↓	C1	C2	C3	C4	C5	C6	C7
	Moisture content	Green strength	Sand particle size	Mould hardness	Trial 1	Trial 2	Trial 3
1	3.2	1200	50	50	6.00	5.30	6.80
2	3.2	1400	52	60	5.10	4.30	5.23
3	3.2	1800	54	75	7.28	5.80	7.64
4	3.8	1200	52	75	3.80	3.40	3.21
5	3.8	1400	54	50	6.34	4.83	7.24
6	3.8	1800	50	60	7.16	6.74	6.17
7	4.3	1200	54	60	6.82	4.32	6.23
8	4.3	1400	50	75	3.21	7.20	4.82
9	4.3	1800	52	50	3.20	3.80	2.72

The S/N ratio found using the smaller the best approach is shown in table 6.

Table 6:- S/N ratio

Worksheet 1 ***

C5	C6	C7	C8	C9	C10	C11	C12
Trial 1	Trial 2	Trial 3	Total	Average	SSQ	SSQ/3	S/N
6.00	5.30	6.80	18.10	6.03333	110.330	36.7767	-15.6557
5.10	4.30	5.23	14.63	4.87667	71.853	23.9510	-13.7932
7.28	5.80	7.64	20.72	6.90667	145.008	48.3360	-16.8427
3.80	3.40	3.21	10.41	3.47000	36.304	12.1014	-10.8283
6.34	4.83	7.24	18.41	6.13667	115.942	38.6474	-15.8712
7.16	6.74	6.17	20.07	6.69000	134.762	44.9207	-16.5245
6.82	4.32	6.23	17.37	5.79000	103.988	34.6626	-15.3986
3.21	7.20	4.82	15.23	5.07667	85.377	28.4588	-14.5422
3.20	3.80	2.72	9.72	3.24000	32.078	10.6928	-10.2909

The effect of a factor level is defined as the deviation it causes from the overall mean. Hence as a first step, calculate the overall mean value of η for the experimental region defined by the factor levels.The overall mean m is given by

$$m = \frac{1}{9}\sum_{i=1}^{9} \eta_i = \frac{1}{9}(\eta_1 + \eta_2 + \cdots + \eta_9)(1)$$

From the equation given$m$ = -14.416

The effect of the moisture content at level A_1 (at experiments 1, 2 and 3) is calculated as the difference of the average S/N ratio for these experiments (m_{A1}) and the overall mean. The same is given as

The effect of moisture content at :

LevelA_1 = $m_{A1} - m = \frac{1}{3}(\eta_1 + \eta_2 + \eta_3) - m(2)$

Level A_2 = $m_{A2} - m = \frac{1}{3}(\eta_3 + \eta_4 + \eta_5) - m(3)$

Level A_3 = $m_{A3} - m = \frac{1}{3}(\eta_6 + \eta_7 + \eta_8) - m(4)$

Using the S/N ratio data available in Table 6the average of each level of the four factors is calculated and listed in Table 7. These average values are shown in Figure 3. They are separate effect of each factor and are commonly called main effects.

Table 7:- Average η for different factor levels

Level	Moisture content	Green strength	particle size	Mould hardness
1	-15.43	-13.96	-15.57	-13.94
2	-14.41	-14.74	-11.64	-15.24
3	-13.41	-14.55	-16.04	-14.07
Delta	2.02	0.77	4.40	1.30
Rank	2	4	1	3

Once the average η for different factor levels are found the S/N vs. factor level was plotted (Table 8).

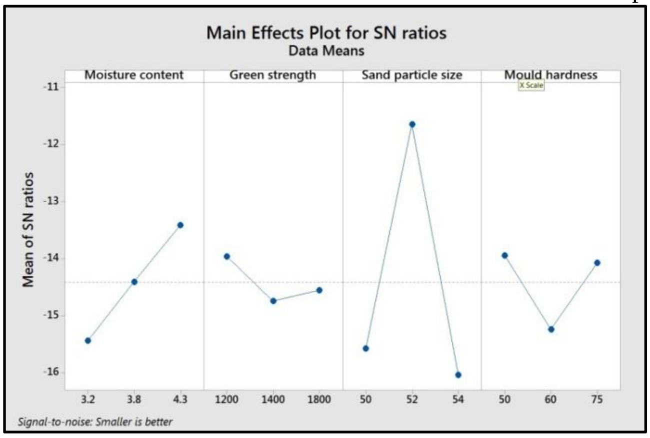

Figure 3:- S/N vs. factor level plot

Our goal in this experiment is to minimize the surface defect counts to improve the quality of the silicon wafers produced through the chemical vapor deposition process. Since –log depicts a monotonic decreasing function [equation 1] we should maximize η. Hence the optimum level for a factor is the level that gives the highest value of η in the experimental region. From Figure 3and the Table 7, it is observed that the optimum settings for moisture content, green strength, sand particle size and mold hardness are A3 B1 C2 D1. Hence we can conclude that the settings A3 B1 C2 D1 can give the highest η or the lowest surface defect count.

Different factors affect the surface defects formation to a different degree. The relative magnitude of the factor effects are listed in Table 7. A better feel for the relative effect of the different factors is obtained by the decomposition of variance, which is commonly called as analysis of variance (ANOVA). This is obtained first by computing the sum of squares

Total sum of squares $=\sum_{i=1}^{9}(\eta_i - m)^2 = 45.24dB^2$(5)

Sum of squares due to factor A

$= [(number\ of\ experiments\ at\ Level\ A1) \times (m_{A1} - m)^2] + [(number\ of\ experiments\ at\ Level\ A2) \times (m_{A2} - m)^2] + [(number\ of\ experiments\ at\ Level\ A3) \times (m_{A3} - m)^2]$(6)

From the equation 6 the sum of squares of each factor is calculated and found out to be:

1) Moisture content (%) = 6.121
2) Green strength (g/cm^2) = 0.331
3) Sand particle size (AFS) = 35.026
4) Mould hardness = 3.075

The ANOVA table is tabulated and the F values are found out

Table 8:- Anova table

Factor	DOF	Sum of squares	Mean square	Fvalue
C. Sand particle size	2	35.026	17.563	
A. Moisture con	2	6.121	3.121	17.142
D. Mould hardness	2	3.075	1.538	3.045
B. Green strength	2	0.331	0.165	
Total	8	45.245		
Error	4	4.0946	1.025	

In the present case-study, the degrees of freedom for the error will be zero. Hence an approximate estimate of the error sum of squares is obtained by pooling the sum of squares corresponding to the factors having the lowest mean square. As a rule of thumb, the sum of squares corresponding to the bottom half of the factors (as defined by lower mean square) are used to estimate the error sum of squares. In the present example, the factors D and B are used to estimate the error sum of squares. Together they account for four degrees of freedom and their sum of squares is 4.095.

The major inferences from the ANOVA table are given in this section. Referring to the sum of squares in Table 8, the factor C makes the largest contribution to the total sum of squares [(35.026/45.245) x 100 = 77%]. The factor A makes the next largest contribution (13.53 %) to the total sum of squares, whereas the factors B and D together make only 9.657 % contribution. The larger the contribution of a particular factor to the total sum of squares, the larger the ability is of that factor to influence η. Moreover, the larger the F-value, the larger will be the factor effect in comparison to the error mean square or the error variance.
In the present case, the optimum condition or the optimum level of factors is A3 B1 C2 D1. The value of η under the optimum condition is predicted using the additive model as

$\eta_{opt} = m + (m_{C2} - m) + (m_{A3} - m) = -10.633(7)$

Since the sum of squares due to the factors B and D are small as well as used to estimate the error variance, these terms are not included in equation 7. The mean square count at the optimum condition is calculated as

$y = 10^{\frac{-\eta_{opt}}{10}} = 10^{1.0633} = 11.569(8)$

The corresponding root-mean square rejectioncount is

$\sqrt{y} = 3.40\ \%(9)$

From the results it can be seen that by selecting the found out factor levels the rejection percentage can be kept at 3.40%.

VII. Conclusions

Casting defects were studied to find out the factors causing it. The reduction of defects was done by optimizing the control variables or factors affecting the output. Taguchi method was the best available method to optimize the factors and together with the help of analysis of variance the optimum control factors were found out. Sand particle size and moisture content account for the main reason for controlling defects. The percentage rejection of the plate cylinders can be reduced to 3.40 % which is a significant improvement in this case. Taguchi method is thus a cost effective method which can be used in industry to reduce the wastage of cast parts with the existing industry resources.

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