Quality Engineering of Impellers used in Water Pumps – A Taguchi Approach

Hemant Kagra & Prashant Sonare

Abstract

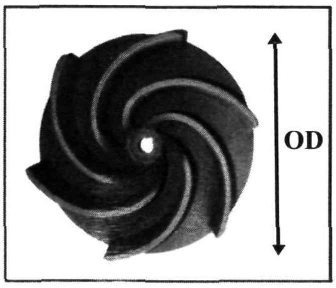
Impeller is a vital component of water pumps and its dimensional accuracy is of utmost importance for reliable working of water pumps. Variation in dimension (Outer Diameter) results in poor fit of the impeller and causes low water discharge as well as reduction of impeller life. More importantly, due to poor fit, impeller jams with the shaft and may damage the entire water pump, resulting in functional & financial losses. Application of conventional quality techniques of Statistical Process Control has not been able to improve the dimensional accuracy. Taguchi technique of quality engineering has been used to design an improved manufacturing process and to reduce the variation in quality. Taguchi techniques incorporate adjusting the Target Control Factors / Variability Control Factors at their optimum levels, so that the quality characteristics can be always on target. The OD of the Impeller is mainly affected by Temperature & Pressure (each having 2 levels) settings. Using DOE technique, an experiment is designed as per the $L_4(2^2)$ standard Orthogonal Array and the analysis of results is done through ANOVA technique. From the analysis, Temperature emerges as the most significant factor in varying the Outer Diameter. Setting the melt temperature at 320°C results in zero error impellers.

Keywords: Impeller, Statistical Process Control, Taguchi Techniques, Design Of Experiments, Orthogonal Arrays, Fractional factorial designs, Injection molding, ANOVA

Introduction - The impeller

An Impeller is a rotating component of a centrifugal pump, which transfers energy from the motor that drives the pump, to the fluid being pumped, by accelerating it outwards from the center of rotation. It has an open inlet to accept incoming fluid, vanes to push fluid radially, and a threaded bore to accept a drive shaft. Impellers are used for high speed / high pressure movement of fluids through a piping system.

Figure 1: Impeller of Water pump



Impellers of a water pump generally consist of two parts – the top and the bottom. It is made of plastic (Polyphenyl Oxide) material and is manufactured as per drawing no. 99401 ver. 04.

The manufacturing process

The various stages in the manufacturing process of this impeller are as follows:

(i) The batch comprising of Polyphenyl-Oxide plastic is heated up to 120°C for removal of moisture.

(ii) The dry batch is then fed in the Hopper.

(iii) The Charge is heated up to 300°C in stages.

(iv) When the charge is completely melted, it is injected in the mould at 290°C - 320°C temperature and 75 – 85 bar pressure.

(v) The pressure is held for 10 sec. and the melt is allowed to cool.

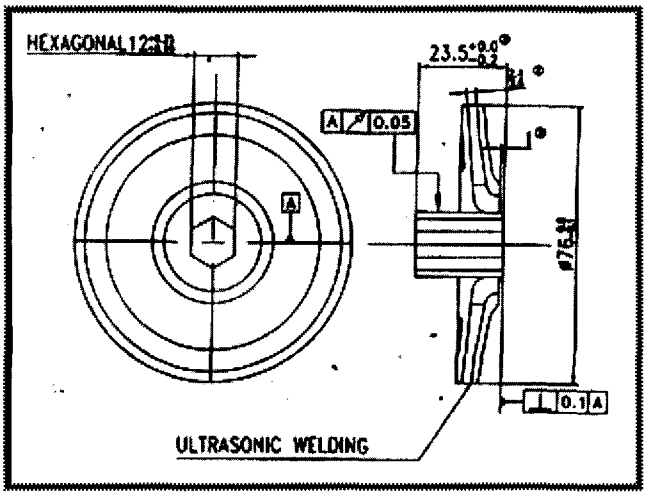
(vi) The Impeller (bottom) is then ejected out and allowed to cool naturally.

(vii) Any excess material is cut off manually with the help of cutters and the rough edges are smoothened.

The Specification

The specification sheet / technical drawing of the impeller is as in Figure 2:

Figure 2 : Technical Drawing No. 99401/4 of Impeller



The dimensions of impeller are as in Table 1.

Table 1: Dimensions of Impeller

Sl. No.	Parameter	Dimension	Tolerance		Unit
1	Outer Diameter	76.00	+ 0.0	- 0.1	mm
2	Bore	12.00	+ 0.25	- 0.1	mm
3	Bore Length	23.50	+ 0.0	- 0.2	mm
4	Boss Outer Diameter	16.40	+ 0.1	- 0.1	mm
5	Vane Gap	2.40	+ 0.2	- 0.0	mm
6	No. of Vane	8			mm
7	Concentricity	0.20 (max.)			mm

Problem - The Reliability Issues

As per the specification, the OD of the Impeller (bottom) should be 76 (+0.0, -0.1) mm. When fitted on the shaft, the deviation in concentricity should be less than 0.20 mm.

There were a lot of customer complaints regarding failure of water pumps. Based on the customer feedback, it was found that in almost all the cases of failure of water pumps, the impeller (bottom) had become loose. On detailed investigation, it was found that the deviation in concentricity of the shaft & impeller was more than 0.20 mm., which was caused by variation in the Outer diameter.

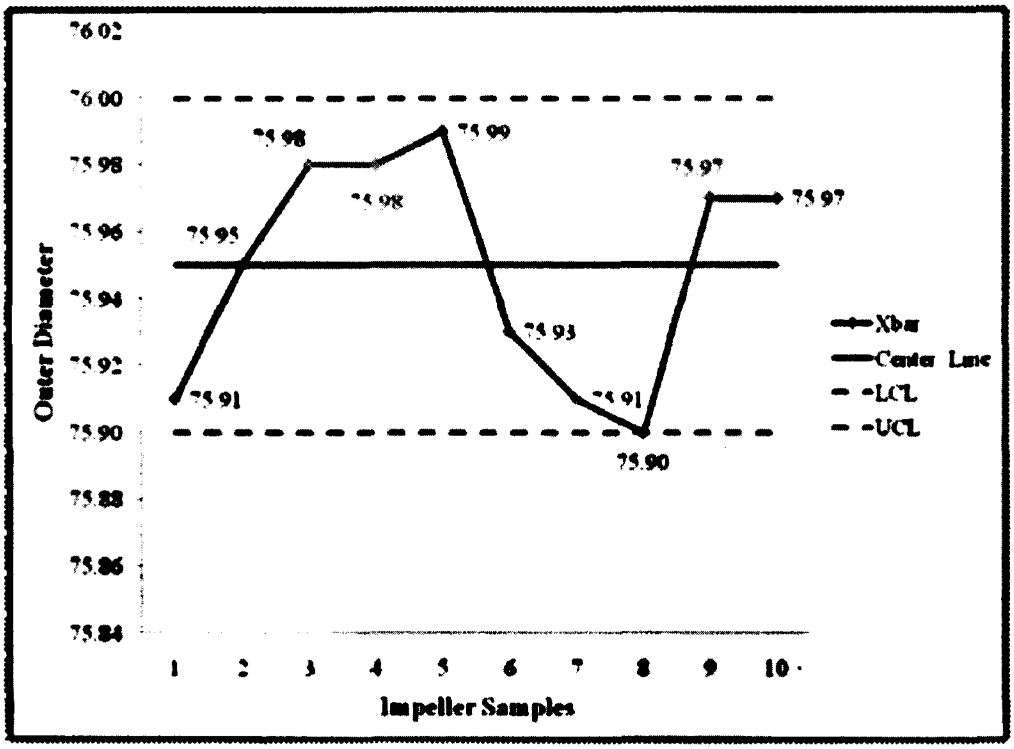
Due to large deviation in the concentricity, the impeller, during high speed rotations, tends to get loose and apart from having rotary motion, starts having a lateral movement also. This lateral movement causes the water flow to be turbulent and upsets the output. This results in reduction in the water discharge of the pump.

Besides, the loose impeller may move from its position and while rotating at high speed, it can get stuck with the shaft and the pump shall become jam and stop working. This shall cause functional as well as financial loss, as the entire pump has to be dismantled and overhauled.

Scope - Constraints of conventional quality techniques

Since most of the customer complaints regarding the water pumps failure were attributable to the non-conformance of outer diameter to the specification parameters, the production process was analyzed and Statistical process control techniques were deployed to maintain the dimensional accuracy of the impeller. However, this met with limited success and the variation in the outer diameter did not cease.

Graph 1: SPC chart for Impeller Outer Diameter (before the application of Taguchi Techniques)



The various drawbacks in this approach were as under:

(i) Although the OD was well within the specified limits, there was large variation in the dimension. SPC aims to maintain the quality characteristics between the specified limits only; thus has very little scope for further improvement in quality of products.

(ii) Highly complex approach–calculation of control & specification limits was tedious; the limits were required to be reassessed frequently and readjusted at regular intervals to ensure process capability.

(iii) Sampling was required to be very frequently, so as to prevent discrepancies and poor quality results to slip through. This was costly and tedious.

(iv) Expert staff required as misinterpreting the common & special causes can not only fail to improve matters, but can also result in disastrous situation.

(v) High cost of quality - Since the processes are to be monitored on-line, high level of expertise and statistical training are required.

(vi) Most importantly, SPC does not take full consideration of the customers' perspective & requirements. The entire focus is on maintaining the processes as robust as possible and within the specified limits. This approach delivers a product which is statistically within the specified limits, but may or may not bring satisfaction to the customer.

Objective

When the SPC techniques failed to yield the desired accuracy, Taguchi Techniques with Design of Experiments was used, to enhance the reliability of impeller and to address the quality issues.

Research Methodology - Application of Taguchi Technique

Defining the Problem

The failure of water pumps was attributable to the non-conformance of outer diameter to the specification parameters.

Determining the Objective

Based on the detailed analysis, the quality characteristic of interest was taken as the Outer Diameter. As per the specification the OD of the Impeller (bottom) should be 76 (+0.0, -0.1) mm.

Conducting Brainstorming Session

A brainstorming session was conducted with the process operator and designer. The probable factors affecting the dimensions of OD are:

Table 2: Factors affecting Outer Diameter

FACTORS	LEVEL 1	LEVEL 2
Die	Existing	New
Material	M1	M2
Material Vendor	V1	V2
Melt Temperature	290°C	320°C
Pressure	75 bar	85 bar

Out of the above, the two controllable factors - Temperature (at 2 levels) & Pressure (at 2 levels) were considered for experimentation.

Designing the Experiment

From the Two Level Orthogonal Array selection table, the minimum required OA table - L4 (2^2) Standard Array, (as given in Table 3) was selected for these 2 factors having 2 Levels each:

Table 3 : The L4 (2^2) Standard Orthogonal Array

Trail No.	Factors		
	1	2	3
1	1	1	1
2	1	2	2
3	2	1	2
4	2	2	1

From the Two Level OA Factor Assignment Table, the 2 factors (factor 1 - Temperature; factor 2–Pressure) were assigned as in Table 4.

Table 4 : Factor Assignment Table

Trail No.	Temperature	Pressure	Interaction
1	1	1	1
2	1	2	2
3	2	1	2
4	2	2	1

As per the Two Level OA Interaction Table, Column No. 3 is for the Interaction Factor – Temperature x Pressure.

Conducting the Experiment

For every trial, two observations were taken. The results of the trial are as in Table 5:

Table 5 : Results of Experimental Trials

Trail No.	Temp (A)	Press (B)	Outer Diameter	
			Observation 1	Observation 2
1	1	1	74.78	75.20
2	1	2	75.80	75.89
3	2	1	75.95	75.96
4	2	2	75.97	75.99

The photographs of the impeller produced in the various trials are as follows:

Figure 3 : Result of Trial No. 1

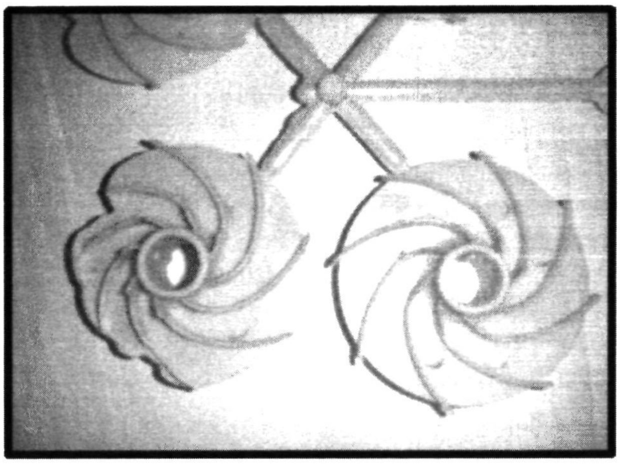


Figure 4 : Result of Trial No. 2

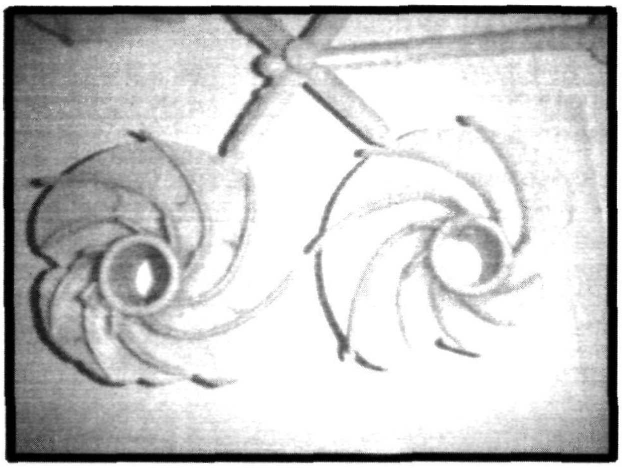


Figure 6 : Result of Trial No. 4

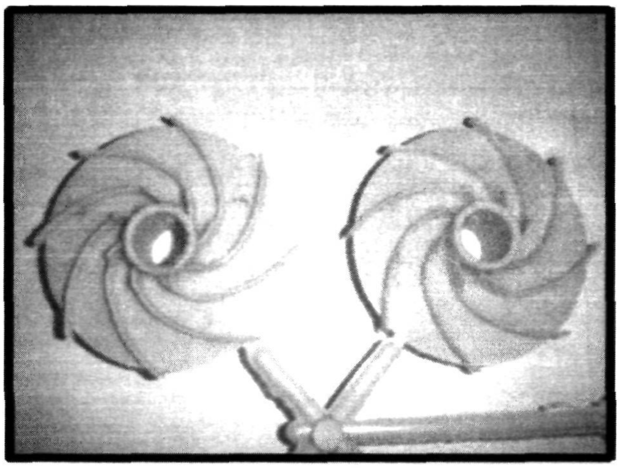
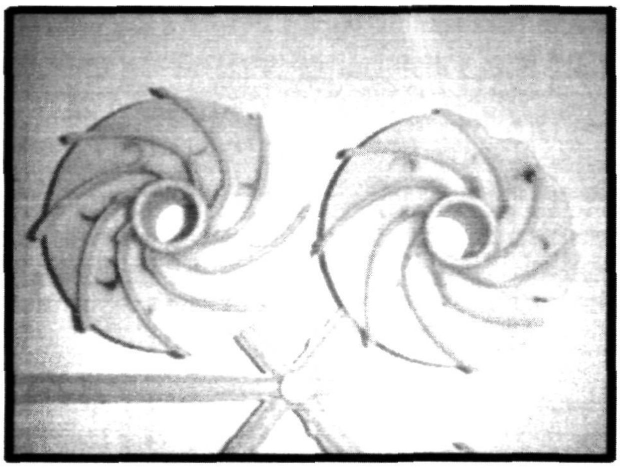


Figure 5 : Result of Trial No. 3



Analyzing the Data

$df_{tot} = 8 - 1 = 7$

$df_A = 2 - 1 = 1$

$df_B = 2 - 1 = 1$

$df_{AxB} = 2 - 1 = 1$

$df_e = 7 - 1 - 1 - 1 = 4$

Table 6 : The ANOVA Table

Factor	*df*	SS	MSS (SS/*df*)	F–ratio (MSS/MSSe)	F-Critical
Temp.	1	0.6050	0.6050	10.5592 *	7.71
Pressure	1	0.3872	0.3872	6.7579	7.71
Temp.x Pressure	1	0.34	0.3444	6.0118	7.71
Residual (Error)	4	0.2292	0.0572		
Total	7	1.5658			
			* Significant at 0.05 Level of Significance		

Interpreting the Results

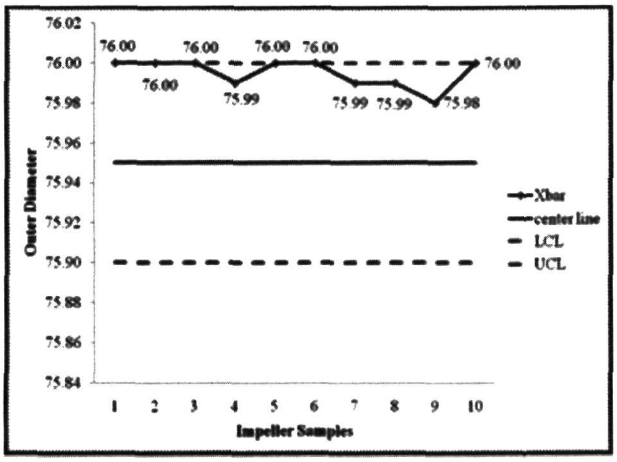
As can be seen from above, Temperature significantly affects the dimension of Outer Diameter. Thus, controlling temperature at its optimal value (320^{0}C) can yield the target value of Outer Diameter.

Running Confirmatory experiment

The experiment was again conducted with temperature setting as 320^{0}C. Total 10 impeller samples were manufactured with this setting and were found to be conforming to the specifications.

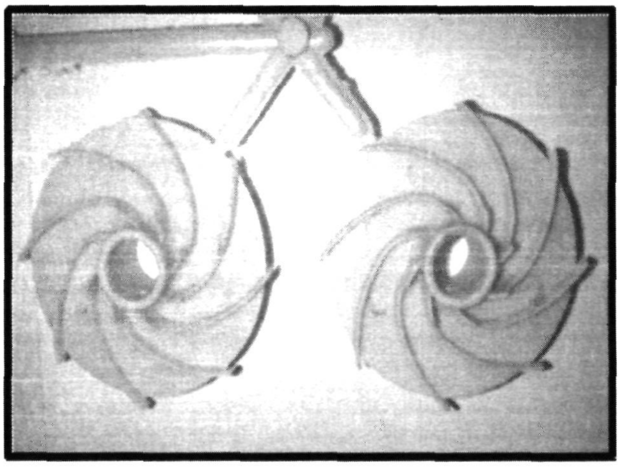
Results and Discussion

Graph 2 : SPC chart for Impeller Outer Diameter (after application of Taguchi Technique)



As can be seen from the Xbar Chart (Graph 2) the Outer diameter of the impeller was well within the specified limits of 76 mm. (+0.0, -0.1). Also, with this temperature setting, obtained from the Design of Experiments, the variation in dimensional accuracy of OD was less than 0.01%.The shape of the impeller was also optimal, as can be seen in Figure 7.

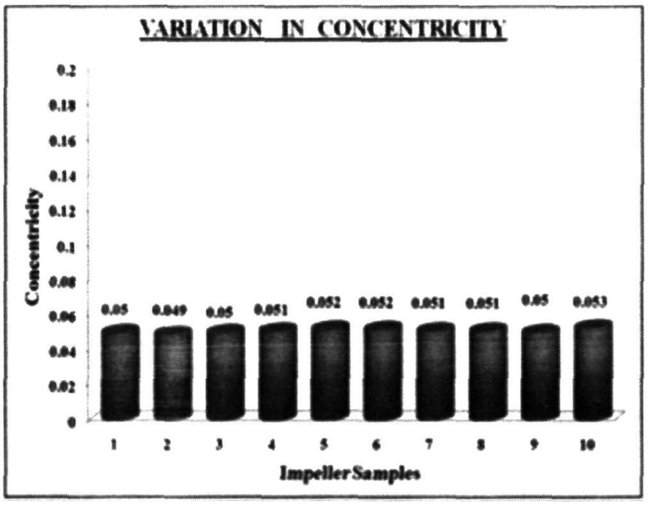
Figure 7 : Result of Confirmatory Experiment



The biggest achievement was that the concentricity was reduced to approx. 0.05 mm., which is the industry target. This is way below the maximum permissible value of 0.20 mm. With better concentricity (i.e. lesser the distance between center of shaft and of the impeller), movement of impeller shall be exactly smooth and rotary and the functional performance of the water pump is considerably improved.

The variation in concentricity for the 10 impeller samples is shown in Graph 3.

Graph 3 : Concentricity of impeller & shaft (after application of Taguchi Technique)



Thus, by the use of Taguchi Techniques, the quality of impeller and in turn, the reliability of water pumps has been enhanced and now the customer complaints have reduced practically to zero on this account.

Conclusion

(i) The variation in OD was very much reduced. Taguchi's Techniques delivers On – target quality. SPC alone cannot ensure enhancement in quality.

(ii) Simplistic approach; Does not require high level training.

(iii) Expenditure only in initial experimentation stage; the recurring cost of maintaining high quality is very low.

(iv) Customers' perspective & requirements regarding quality are taken into consideration.

Limitations of Taguchi Techniques

(i) Adopting Fractional – factorial designs (Orthogonal Arrays) undermines effect of some of the higher order interactions.

(ii) The higher order interactions can't be analyzed.

(iii) In certain situations, the noise factors can't be identified precisely due to which the accuracy of Signal – to Noise Ratio (SNR) is compromised.

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About the Authors:

Hemant Kagra is a Research Scholar at JJT University, Mumbai, India. The author can be reached at hemantkagra@yahoo.co.in

Prashant Sonare is the Principal of SSJCET, Asangoan, Mumbai, India. The author can be reached at prashantsonare@yahoo.co.in