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Regression Modelling and GRA, RSM Comparison Between Parameters and Performance Characteristics in a TOBV

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Abstract – Triple offset butterfly valves are widely used in hydraulic, sewage, oil and gas pipelines. Seating torque and deformation of the disc are the important characteristics to be considered during the assessment of flow performance of butterfly valves. In order to minimize the leakage in pipelines, the offset concept was introduced in butterfly valves by designers. Even though some of the researchers have studied the effect of offset on sealing characteristics of butterfly valves, studies considering the effect of offsets on the performance characteristics such as seating torque and deformation of the disc have not been reported yet. Hence the present project focuses on parametric study of triple offset butterfly valves in order to maximize the flow performance and hence achieve optimal combinations of valve parameters.

The overall objective of the study is to evaluate the effect of offset in a TOBV on the characteristics of the valve like seating torque and disc deformation. The geometry considered for this purpose is TOBV DN100 CLASS150 valve. Triple offset butterfly valve CAD model was generated using SOLIDWORKS V 13. The same CAD model was then imported to ANSYS Workbench platform to conduct static structural analysis of the valves. Simulation runs were designed based on Taguchi's Orthogonal Array approach. The offset having the maximum influence on seating torque and disc deformation were evaluated. A regression model for seating torque and disc deformation was also developed indicating good correlation. The optimal combination of offset levels for minimum seating torque and minimum disc deformation were also evaluated through Grey Relation Analysis and Response Surface Methodology. Both were found to be in good agreement.

1. INTRODUCTION

Butterfly valves are high pressure recovery valves i.e which gives relatively low pressure drop across the disc when the valve is in full open condition as compared to globe valves. They are known to be line size valves where the inlet and outlet of the pipeline in which the valve is installed has the same diameter as that of the nominal diameter of the valve. Low cost of installation and high sealing capability is one of the most important advantage of a butterfly valve. A typical butterfly valve consists of body, disc, stem, seal, bearing and seat as the major components in the valve.

Over the years many concepts have been developed to improve the sealing characteristics of a butterfly valve. One of them is providing the offset in the valve. A TOBV is consisting of three offsets for improvement in the performance characteristic of the butterfly valve. The first offset represents offset between the centerline of the stem and the mid plane of the disc. A butterfly valve includes valve housing with a circular cylindrical bore about a centerline providing a fluid passage through the housing. A valve seat surface is formed around the interior of the valve body for engagement of the periphery of the disc in valve closed position.

The valve seat surface is a section of an elliptical cylinder whose centerline intersects the body centerline at angle as shown in Fig 1.1. A shaft is mounted across the body normal to its center line. A disc is mounted on the shaft for rotation and is offset relative to the shaft that is the disc plane is placed at a distance from the centerline of the stem. The disc has a circular periphery in a plane parallel to the shaft. [1]

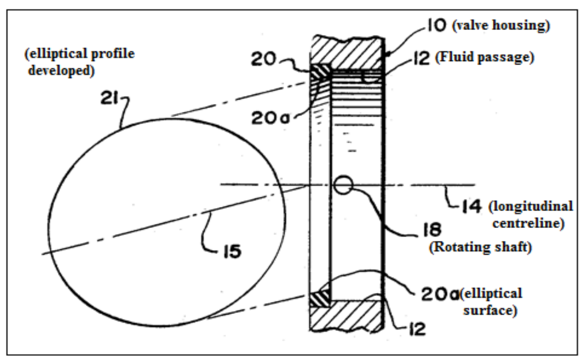

Fig 1.1 Sectional view normal to the axis of disc

In order to fully comprehend the manner, in which a circular closure disc may be seated on an elliptical cylindrical surface it should be understood that the line of intersection of a circular cylindrical surface by a flat plane oriented obliquely to the elements and centerline of the cylinder, produces an elliptical curve. Also the intersection of an elliptical cylindrical surface by a flat plane passing through the cylinder at an appropriate angle to the cylinder elements produces a circle. In Fig 1.2 the developments 23 and 24 show the outer and inner edges of the valve seat formed by the intersection of the planes form circles of substantially the same diameter as the valve disc.

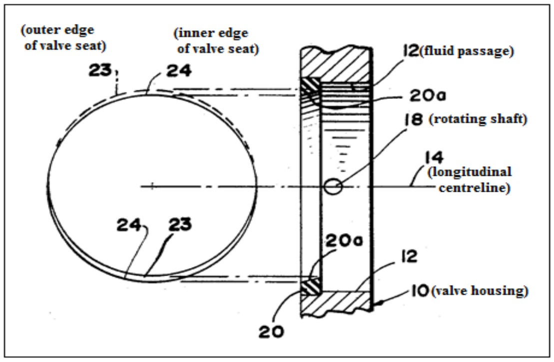

Fig 1.2 Sectional view the development of surface intersected by a perpendicular plane

In second offset valve stem is centered to the disc along its face. In the present invention the stem is positioned off center to the centerline of the disc along its face.

This provides a longer and a shorter extension of the disc across the flow way. The body is having two stops by means of which it can engage the opposite side of the disc when the disc is in closed position transverse to the flow in the flow way.

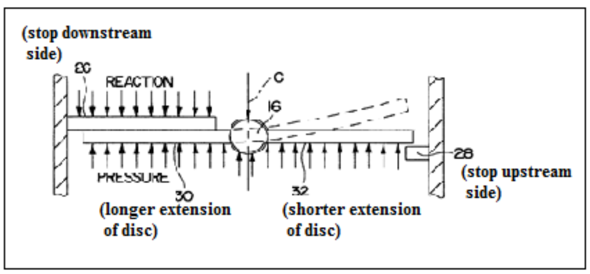

Fig 1.3 Diagrammatic view illustrating prior art centered stem

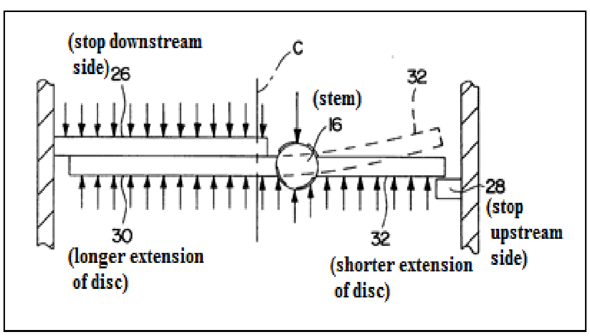

Fig 1.4 View illustrating minimized deflection of disc

The first stop engages the longer side of the disc and the second stop engages the shorter side of the disc in the upstream side of the flow when the disc is in closed position. This is effective to reduce deflection of the disc and rotation of the valve stem and thus reduce or prevent leakage flow past the disc. [2]

In the third offset A butterfly valve consists of a housing in which a flat plate having an elastic rim is adapted to turn between a position in which the flap plane is parallel to axis of flow and a position in which the elastic rim is in sealing relationship to a seat around the axis of passage across the housing. The seat is having a shape of a cone surface, the apex of the cone being located outside the axis of flow. Thus the sealing surface of the seat forms part of an oblique circular cone the circular base of which being at right angles to the axis of the flow. The axis of such cones forms an angle with the axis of the flow as shown in Fig 1.5. Now cross sections of such cones in planes not at right angles to the axis of the cone are ellipses. [3]

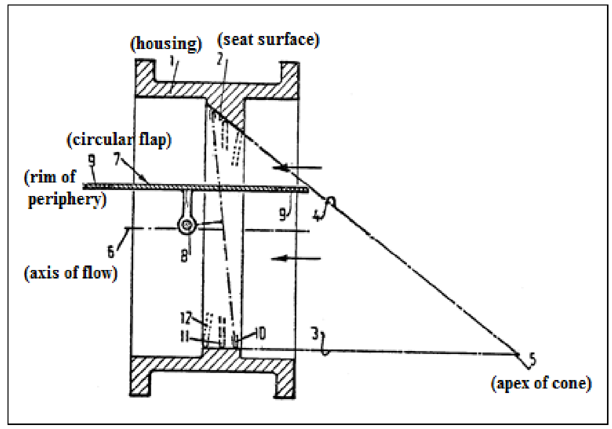

Fig 1.5 Longitudinal sectional view of the housing

With the valve operation the circular disc shape is getting deformed at different positions in the seating surface which can contribute for efficient seating of the disc with the seating surface.

The literature survey indicates that the torque analysis is mainly focused with symmetric disc. Also the hydrodynamic torque analysis in et al [4] is done based on only second offset. But the effect of offsets on the seating torque in a TOBV is yet to be reported.

The purpose of this paper is to validate the offset concept by finding the disc deformation in the analysis platform and conduct a design of experiments for the seating torque using Taguchi approach.

2. STRUCTURAL ANALYSIS OF TOBV

A. TOBV Model development

A typical butterfly valve consists of around 20 parts involving complex assembly. In the current study since the effect of offset on the torque and deformation is in the focus a simple model with only 6 parts incubating the different offset as explained earlier has been developed.

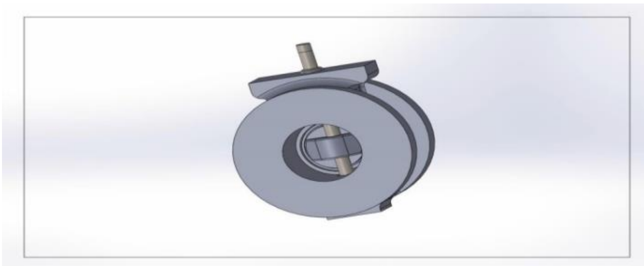

Fig 2.1 Assembly part CAD model

The model is developed in design platform SOLIDWORKS V13.

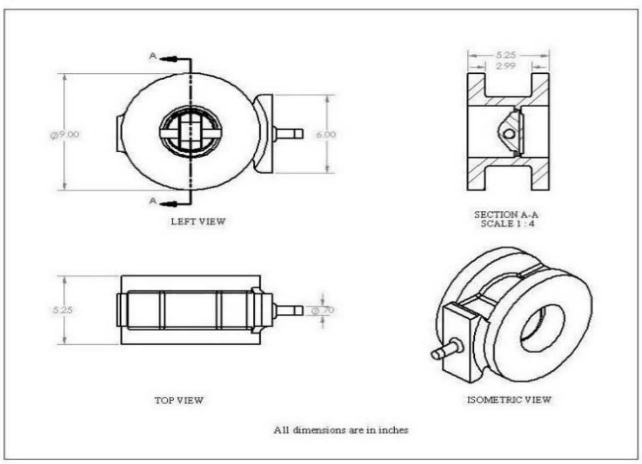

Fig 2.2 General Assembly drawing for TOBV DN 100 CLASS 150

B. Finite Element Analysis

i. Contacts:

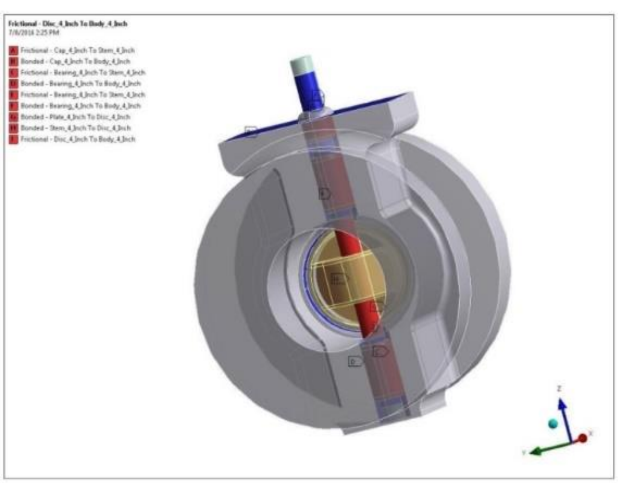

Fig 2.3 The type of contact between surfaces of TOBV in ANSYS

The coefficient of friction between all the contact surfaces in the geometry is taken to be 0.25.

ii. Meshing Details

- Body: 25 mm
- Disc, stem, plate, bearings: 4 mm
- Contact face between body and disc: 4 mm

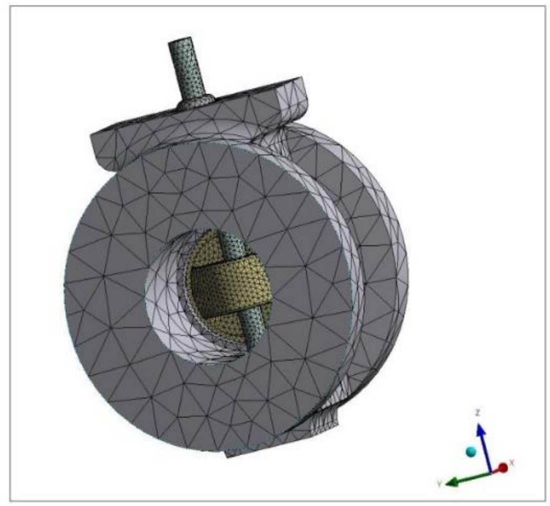

Fig 2.4 Tetrahedron mesh of TOBV in ANSYS

- Meshing method: Tetra conforming method
- Type of mesh: Tetrahedron having 4 vertices, 6 edges and is bounded by 4 triangular faces

iii. Supports and Loadings

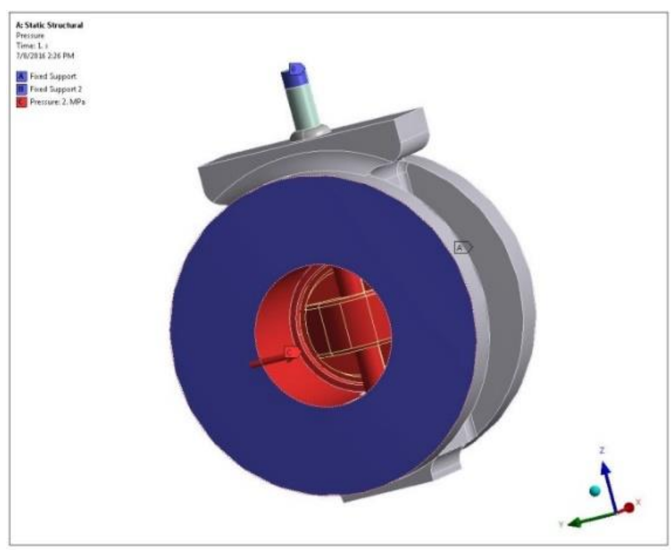

Fig 2.5 Support and Loading conditions of TOBV in ANSYS

Fixed support 1: On the flange edges of the body.

Fixed support 2: Top and bottom portion of the stem.

Pressure applied: 2 MPa on the disc portion.

3. DESIGN OF EXPERIMENTS

The experiments are designed based on L_8 Taguchi's orthogonal array considering the parameters as offset 1, offset 2 and offset 3. The Seating torque and Disc deformation is selected to be the response.

Table 3.1 parameters and levels selected for the analysis

	Parameters/Factors	Levels	
		1	2
1	Offset 1 ; O1 (inch)	0.5	0.6
2	Offset 2 ; O2 (inch)	0.14	0.2
3	Offset 3 ; O3 (degrees)	20	28

Table 3.2 L_8 ORTHOGONAL ARRAY LAYOUT

Expt. No.	Parameters/Factors		
	Offset 1 ; O1 (inch)	Offset 2 ; O2 (inch)	Offset 3 ; O3 (degrees)
1	0.5	0.14	20
2	0.6	0.14	20
3	0.5	0.2	20
4	0.5	0.14	28
5	0.5	0.2	28
6	0.6	0.14	28
7	0.6	0.2	20
8	0.6	0.2	28

4. RESULTS AND DISCUSSIONS

The Disc deformation of the triple offset butterfly valve is represented in the figure 4. The result for experiment no 1 is represented in the above figure 4. Similarly the results are obtained for all the iterative models considered to evaluate the effect on offset on the deformation and the torque in the assembly. As proposed with the second offset the maximum deformation in the assembly occurs at the end of the short edge of the disc which is represented in the above figure. The torque reactions at different contact region in the direction of the applied load are recorded to evaluate the effect of offset on torque and also to establish the mathematical model between the torque and the offset considered.

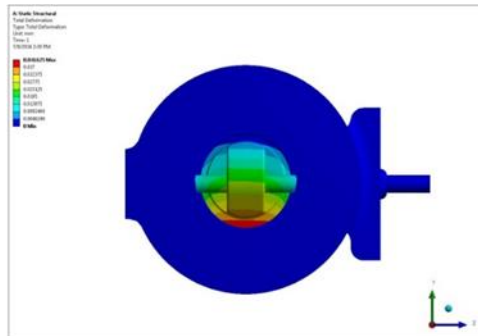

Fig 4.1 Solution result for Disc Deformation in TOBV

Table 4.1 Response for Disc Deformation

TOBV MODEL	DISC DEFORMATION in mm
1	0.047479
2	0.046028
3	0.04189
4	0.042409
5	0.039303
6	0.041943
7	0.040553
8	0.039027

Table 4.2 Response for Seating Torque

TOBV MODEL	T.R 1 (N-mm)	T.R 2 (N-mm)	T.R 3 (N-mm)	T.R 4 (N-mm)	T.R 5 (N-mm)	T.R 6 (N-mm)	SEATING TORQUE (N-mm)
1	448.26	8828.2	8701.8	37163	18760	190.84	74092.1
2	393.93	8117.2	7955.7	40517	17900	266.52	75150.35
3	423.65	6876.8	6810.8	40624	21009	229.79	75974.04

4	400.18	8059	7921	36388	26977	219.59	79964.77
5	395.46	7035.4	6989.6	39049	41889	292.32	85733.08
6	398.72	7641.3	7389.5	40212	26178	256.82	82076.34
7	422.09	6310.6	6201.4	43213	20043	226.61	76416.7
8	407.12	6615.6	6490.8	45255	28219	217.06	87204.58

5. ANOVA

Table 5.1 ANOVA for Seating Torque (N-mm)

Factors	Sum Of Squares	Degrees Of Freedom	Mean Square	F_{CAL}	F_{TAB}	P
Offset 1 (O1)	3173914.93	1	3173914.93	1.53	7.71	0.279
Offset 2 (B)	24657191.33	1	24657191.33	11.89	7.71	0.206
Offset 3 (C)	138990963.2	1	138990963.2	67.07	7.71	0.001
Error	8289272.14	4	2072318.03			
Total		7				

Table 5.2 ANOVA for Disc Deformation (mm)

Factors	Sum Of Squares	D.O.F	Mean Square	F_{CAL}	F_{OBS}	P
Offset 1 (O1)	0.000001557	1	0.000001557	1.677	7.71	0.265
Offset 2 (B)	0.00003649	1	0.00003649	39.23	7.71	0.003
Offset 3 (C)	0.00002200	1	0.00002200	23.7	7.71	0.008
Error	0.000003713	4	0.000000928			
Total	0.000063767	7				

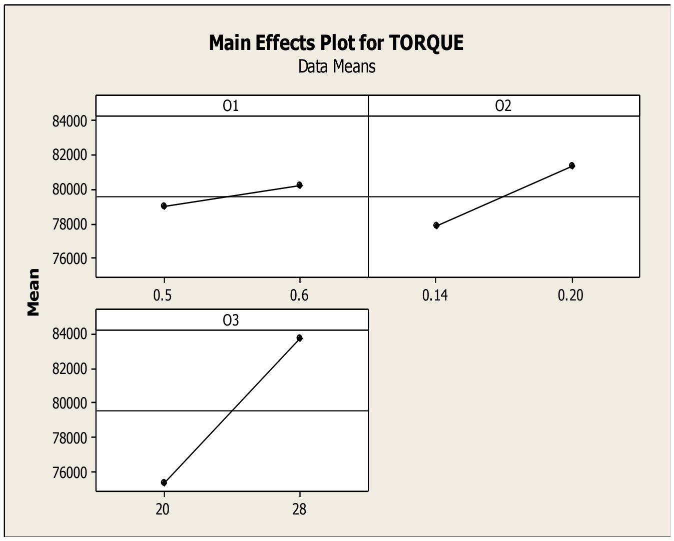

Fig 5.1 Main effect plot for Seating Torque in TOBV

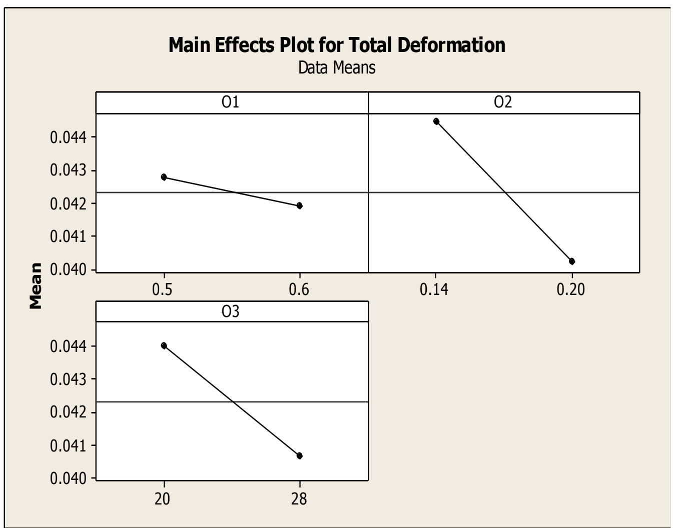

Fig 5.2 Main effect plot for Disc Deformation in TOBV

SUMMARY

ANOVA was done for all then responses and the F_{cal} values were compared with the F_{tab} values to know the significant control factors for each of the responses. The Seating Torque was mainly influenced by the Offset 3. . Increase in offset 3 increased the Seating torque The Disc deformation was mainly influenced by Offset 2. Increase in offset 2 increased the disc deformation.

The regression equation can be given by

Seating Torque = 37628 + 12710 (O1) + 58520 (O2) + 1042 (O3

Disc Deformation = 0.0692 – 0.00883 (O1) - 0.0712 (O) – 0.000415 (O3)

6. GREY RELATION ANALYSIS

Table 6.1 Grey relation analysis results

Expt. No	Orthogonal array			Grey relation coefficient		Grade	Grey order
	O1	O2	O3	Seating Torque	Disc Deformation		
1	0.5	0.14	20	1	0.333333	0.666667	3
2	0.6	0.14	20	0.861022	0.376414	0.618718	6
3	0.5	0.2	20	0.776973	0.596135	0.686554	2
4	0.5	0.14	28	0.527499	0.555468	0.541484	7
5	0.5	0.2	28	0.360288	0.938694	0.649491	5
6	0.6	0.14	28	0.450896	0.591711	0.521304	8
7	0.6	0.2	20	0.738245	0.734701	0.736473	1
8	0.6	0.2	28	0.333333	1	0.666667	4

Table 6.2 Average grade of grey relation coefficients

Levels	Factors		
	Offset 1	Offset 2	Offset 3
1	0.63604	0.58704	0.677103
2	0.63679	0.68479	0.594736
	Level 2	Level 2	Level 1

SUMMARY

The GRA was done by using Microsoft excel sheet to calculate the grey relation grades of the responses. Grey Relational Analysis predicted the minimum deformation of 0.0405 mm and minimum seating torque of 76.41 N-m at second level of offset 1 (0.6 inch), second level of Offset 2 (0.2 inch) and first level of offset 3 (20 degrees).

7. RESPONSE SURFACE METHODOLOGY

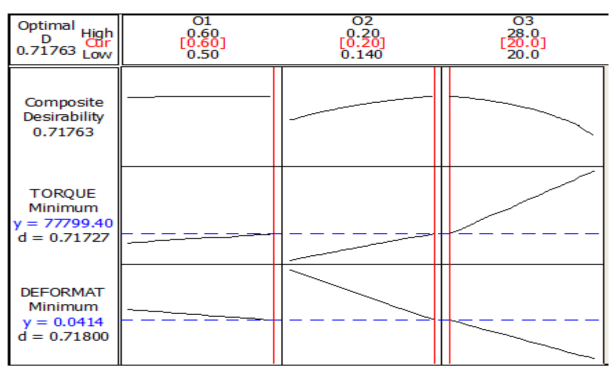

Fig 7.1 Multi objective response optimization

SUMMARY

The values of the responses were fed to MINITAB-16 software to get optimum values of the response. Response surface methodology also indicated the minimum torque of 77.79 N-m and minimum disc deformation of 0.0414 mm at second level of offset 1 (0.6 inch), second level of Offset 2 (0.2 inch) and first level of offset 3 (20 degrees). Both RSM and GRA were found to be in good agreement.

8. CONCLUSIONS

The following conclusions are derived from the assessment of performance characteristics of TOBV employed in pipelines.

- The ANOVA for Seating Torque indicated that Seating Torque was mainly influenced by offset 3. Increase in offset 3 lead to increase in the seating torque. This is mainly attributed to the increase in the seating area at which the pressure of the fluid is applied.
- The ANOVA for Disc Deformation indicated that the disc deformation was mainly influenced by offset 2. Increase in offset 2 lead to decrease in the Disc Deformation. This is mainly attributed to the shortened disc length on the side which is free from stop in the direction of pressure of fluid applied.
- The R-Square values of regression models of seating torque (95.2%) and disc deformation (94.7%) indicated good correlations between the performance characteristics and offset parameters.
- Grey Relational Analysis predicted the minimum deformation of 0.0405 mm and minimum seating torque of 76.41 N-m at second level of offset 1 (15.24 mm), second level of Offset 2 (5.08 mm) and first level of offset 3 (20 degrees). Response surface methodology also indicated the minimum torque of 77.79 N-m and minimum disc deformation of 0.0414 mm at second level of offset 1 (15.24 mm), second level of Offset 2 (5.08 mm) and first level of offset 3 (20 degrees). Both GRA and RSM were found to be in good agreement.

9. FUTURE SCOPE OF WORK

Prototype development incorporating the varying values for the three offsets would help in analyzing torque more accurately.

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