Design & Analysis of Eccentric Rotary Plug Control Valves

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ABSTRACT:

The eccentric rotary plug control valve features an eccentrically mounted plug one company arises a problem while operating eccentric rotary plug that there is less flow rate, friction occurs between the top surface of plug and seat ring and damage valve body due to plug opening. For that design modification has done using UG-NX software and then analysis with ANSYS software. In CFD analysis new valve body has internal pressure 5 MPa. After simulation, the maximum stress of 136.59 MPa of new valve body is observed at 22^{0}c with maximum pressure of 10 MPa which is below the yield strength of the material. After experimentation & calculation Flow rate of water, fuel and LPG gas are 139.51m^3/hr,416.90m^3/hr& 315.06m^3/hr simultaneously. New design overcomes the damage and friction between seat ring and plug, with successful increase in flow rate of valve.

Key words: Rotary plug control valve, Flow rate, UG-NX, CFD, ANSYS.

I. INTRODUCTION

The eccentric rotary plug control valve features an eccentrically mounted plug, which combines rotary valve efficiency with globe valve ruggedness.Its design includes the cam action, low friction plug operation that provides tight shutoff over long service life in a wide variety of flow control applications. The plug is offset to the shaft centerline. This allows the plug to break free of the seat ring immediately upon initial rotation of the shaft. There is no sliding contact between the plug and the seat ring throughout travel, seat ring life and shutoff capability are increases greatly(1).

This inventive design allows orbital movement of the seat ring to provide self-alignment with the plug at assembly. When seat ring is made with plug alignment then seat is locked in place by the seat ring retainer(2). The seat ring and plug rigidly mate with every closure of the valve, maintaining excellent shut off capability. In this valve working fluid is water, LPGgas, steam and non-corrosive fluid like petrol and diesel in environmental temperature at maximum pressure 10 Mpa as per costumer requirement.

Figure 1:- Eccentric Rotary Plug Control Valve

Eccentric rotary plug control valve is not IBR certified but the design is as per IBR. The flanged or flangeless valves feature is dependable service in slurry applications. Mining, petroleum refining, power, and pulp and paper industries use these valves.

II.PROBLEM DEFINITION

One company arises a problem while operating eccentric rotary plug that there is less flow rate and also friction occurs between the top surface of plug and seat ring.It has only a 60 degree opening of the plug with minor leakages.Due to plug opening damage of valve body observed many time. As per customer requirement the flow rate of water has to maintainupto 150m^3/hr. After study of this valve it observed that to Design & Development of eccentric rotary plug control valve is necessary for complete opening without damage of valve body.

III. OBJECTIVES

1. To study existing valve design
2. To Study & Formulate Process Flow Diagram
3. To study material of valve
4. To find Causes of Failure

- Failure due to design of valve
- Failure due to input parameter

IV. TESTING OF MATERIAL

Material suitability is most important thing in valve because various type's fluids, liquid, and gases are flow through this valve. In this case material selection of valve is very important. Properties of material should have good quality, less corrosive and high strength. In existing valve the company used ASTM A479 (SS316), ASTM A564 GR 630 and ASME A216 GR WCB (Cast Iron) material for valve.

Table I.:- Valve Material and their

Properties (4, 5)

Material	Properties	
ASTM A479 (SS316)	1. It has lower carbon content which avoids inter granular corrosion. 2. It is affected to stress-corrosion cracking.	1. These grades offer tensile, creep and stress-rupture strength in higher-temperature applications. 2. It gives better resistance to atmospheric and mild environments.
ASTM A564 GR 630	1. It has high carbon stainless- steels that are hardened to achieve excellent mechanical properties. 2. These steel are achieve high strength & hardness heat treatment.	1. These grades are used in manufacture of long shafts. 2. Those shafts not require re-straightening after heat treatment.
ASME A216 GR WCB	1. Carbon steel castings are used for manufacturing valves, fittings, flanges and other pressure-containing parts.	1. These grades are cast grades. 2. These grades are manufacturing for casting in this procedure a liquid material is poured into a mold and allowed to harden.

These materials are test on UTM machine for yield, tensile, elongation and reduction test. BHN also check on Brinell hardness testing machine. Test and their readings are as below table II shows mechanical properties and table III shows chemical properties:-

Material	Required Test	Yield MPa	Tensile MPa	Elonga-tion area% 50mm	Redu-ction area %	Hard ness BHN
ASTM A479 (SS316)	Min	239	550	40	62	180
	Max	255	565	44	66	185
ASTM A564	Min	860	1102	10	45	330

GR 630	Max	875	1115	12	49	340
ASME A216 GR WCB	Min	250	485	22.0	35.00	--
	Max	--	655	--	--	200
	Actual	322	520	30.0	50.43	188

Table II. Mechanical Properties of Valve Material [3]

Table III. - Chemical Properties of Valve Material [3] in %

Material	**Element**	**C**	**Mn**	**Si**	**P**	**S**	**Cr**	**Ni**	**Mo**	**Nb + Ta**	**Cb – Nb**	**Ta**	**Cu**	**V**	**CE**
ASTM A479 (SS316)	Min	0.024	0.53	0.055	0.034	0.026	16.00	10.00	2.00	--	--	--	--	--	--
	Max	0.030	0.60	1.00	0.045	0.030	18.00	14.00	3.00	--	--	--	--	--	--
ASTM A564 GR 630	Min	0.024	0.53	0.43	0.026	0.012	15.29	4.20	0.14	0.20	0.20	0.001	3.3	--	--
	Max	0.030	0.60	0.49	0.028	0.018	16.02	4.30	0.17	0.20	0.23	0.001	3.5	--	--
ASME A216 GR WCB	Min	--	--	--	--	--	--	--	--	--	--	--	--	--	--
	Max	0.300	1.000	0.600	0.035	0.035	0.500	0.500	0.20	--	--	--	0.3	0.03	0.50

V. DESIGN OF VALVE

As seen previously to solve this problem using trial and error method. After overall study and required specification decides to change in valve body designin UG-NX software [3]. In this case angle of valve plug rotated only at 60^0 because of this less flow rate is obtained. To increase the flow rate and avoid friction plug it requires maximum angle to open around (90^0). Valve body is trimmed from inner side which ultimately gives the addition rotation of plug around 70^0, 80^0 & 90^0. And increases inner diameter of valve but the outer diameter has kept as it is. As per customer requirement the flow rate of water has to maintain up to $150m^3$/hr.

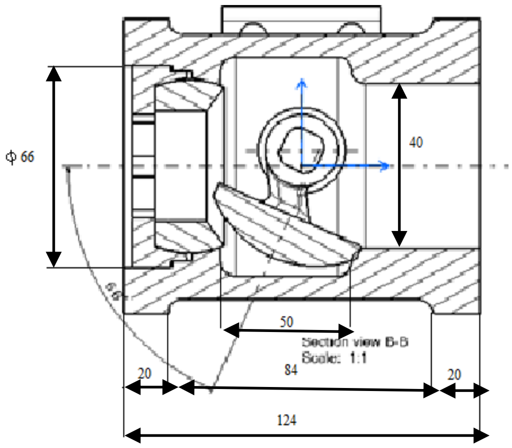


Figure 2:- Cross Section View of existing Valve body

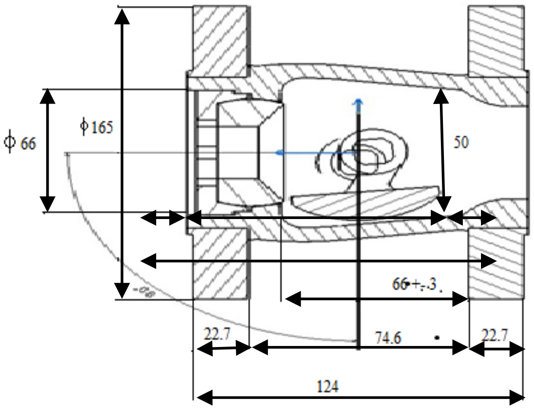


Figure 3:- Cross Section View of old Valve body

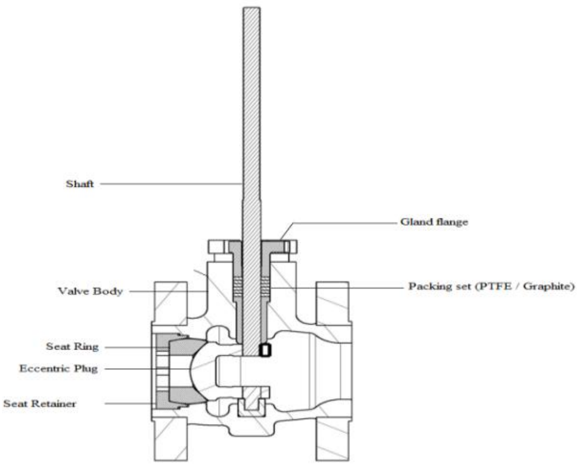


Figure 4:- Design of Valve Assembly

VI. DESIGN CALCULATION OF VALVE

In this design calculation here using formulas as given below:-

Valve body thickness is as per ASME A216-2009 standard:

T= 0.058 D_i + 3.30

Where, T = Shell wall thickness

d = Diameter

1. Circumferential stress

$$\sigma c = [Pi(Do^2 + Di^2)] \div (Do^2 - Di^2)$$

2. Radial stress

$$\sigma r = Pi$$

3. Longitudinal stress

$$\sigma \iota = (Pi \times Di^2) \div (Do^2 - Di^2)$$

Following parameters are used in design calculation and also results are given below:-

TABLE IV: - DESIGN CALCULATION

Parameter	Old valve	New valve
Inner diameter Di	40 mm	50 mm
Outer diameter Do	50.62 mm	72.2 mm
Thickness	5.62 mm	6.2 mm
Pressure Pi	10 MPa	10 MPa
Circumferential stress	85.36 MPa	115.22 MPa
Radial stress	10 MPa	10 MPa
Longitudinal stress	37.68 MPa	52.6 MPa

From the above calculation the circumferential stress is maximum but it is less than the yield stress as 250 MPa so the design is safe.

VII. CFD ANALYSIS

The Reynolds number (Re) is the most important non-dimensional number in fluid dynamics and is recommended to be calculated before any new CFD modeling project.

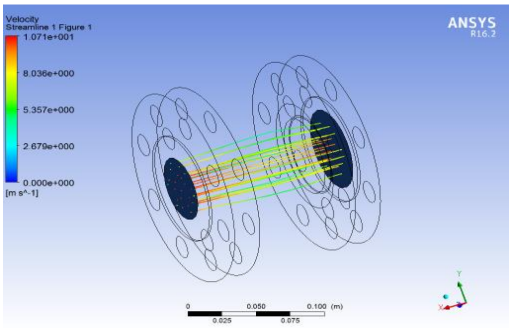
For flows in a pipe of diameter or non-circular pipes with hydraulic diameter, empirical studies have shown that laminar flow occurs for *Re*< 2500 and fully developed turbulent flow occurs for *Re*> 4000.

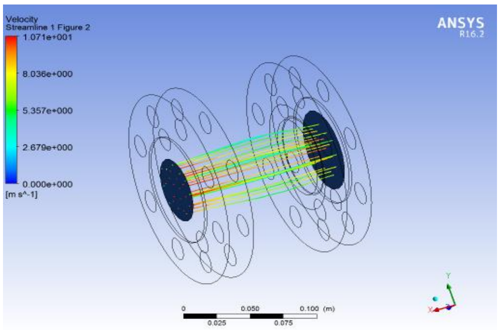
$$\text{Reynolds Number} = \frac{\text{Fluid Velocity} \times \text{Internal Diameter}}{\text{Kinematic Viscocity}}$$

Re is less than critical value so flow is laminar.That's why Laminar flow is considering in CFD analysis.

In CFD analysis we have considered left side of valve as inlet and to the right as outlet valve body. At inlet initial mass flow rate at 1 bar pressure drop is 44.1m^3/hr at 22^{0}C. For valve body we have assigned material properties of structural steel and for fluid as water. Due to complexity of newly designed eccentric valve, Tetrahedral Meshing and laminar flow is carried out in order to get better result. CFD analysis is carried out using ANSYS fluent solver.

After CFD analysis valve has internal pressure 5MPa. The pictures of CFD analysis is as shown below:-





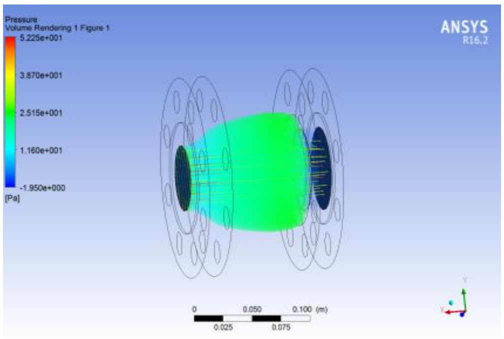


Figure 5:- CFD Analysis result

VIII. ANALYSIS OF EXISTING AND NEW VALVE

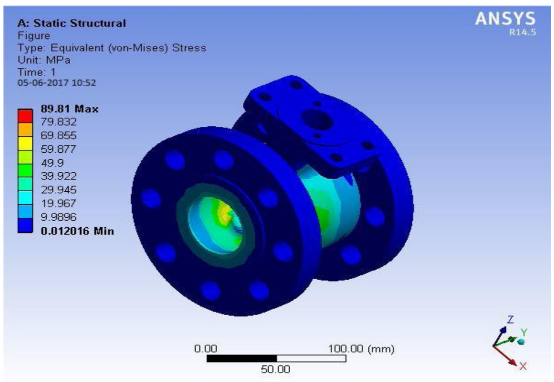
As per customer requirement and for better safty the maximum pressure of 10 Mpa is applied on inner surface of eccentric rotary valve at temperature 22^0 C. In this analysis we have used structural steel material for analysis.

A. Analysis of existing valve body in ANSYS software

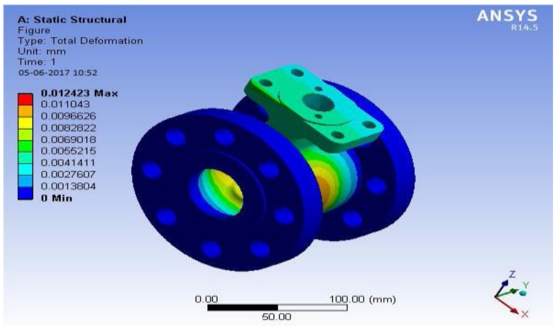
For analysis of existing design of valve body, structural steel material is used. The maximum yield stress of structural steel is 250 Mpa. Due the complexity of newly designed eccentric valve, Tetrahedral Meshing is carried out in order to get better result. Total 8808 Elements and 16635 nodes are generated.For boundary condition, the internal pressure of 10 Mpa is applied on inner surface of wall of eccentric rotary valve at 295.15 K. Simulation is carried out for 1secusing ANSYS. Resultsare found as shown below:-

Table V: - Result Stresses on valve body

Results	Equivalent Stresses	Total Deformation
Minimum	1.2016 -002 MPa	0. mm
Maximum	89.81 MPa	0.012423-002 mm



(6-a)- Equivalent stresses on valve body



(6-b)- Total Deformation of valve body

Figure 6:- Equivalent Stress & Total Deformation Results in ANSYS of existing valve body

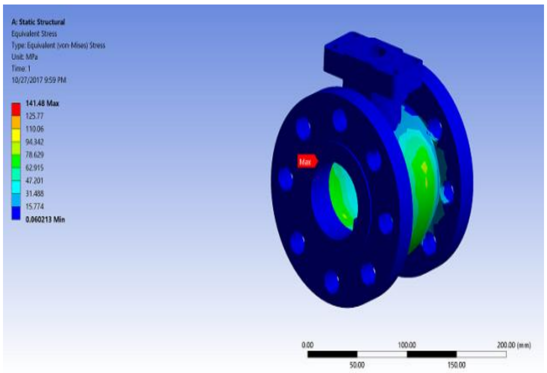
Maximum Stress of valve body is 89.81 Mpa as shown in figure. In this case maximum stress is 89.81 MPa< 250 Mpa so design is safe. Maximum deformation of valve body is 0.012423 mm as shown in fig. (6-a) &(6-b).

B. Analysis of new valve body in ANSYS software

In analysis of new design of valve body there is structural steel material is used. In this case the maximum yield stress of structural steel is 250 Mpa. In ANSYS software pressure applied on Valve Body is 10 Mpa at 22^{0}C. Statistics of this design are Nodes- 14646 & Elements- 8144. After generate this design in ANSYS software with this material in 0-1 second the result are found as shown below:-

Table VI: - Result Stresses on valve body

Results	Equivalent Stresses	Total Deformation
Minimum	5.8128e-002 MPa	0. mm
Maximum	136.59 MPa	0.0264-002 mm



(7-a) - Equivalent stresses on new valve body

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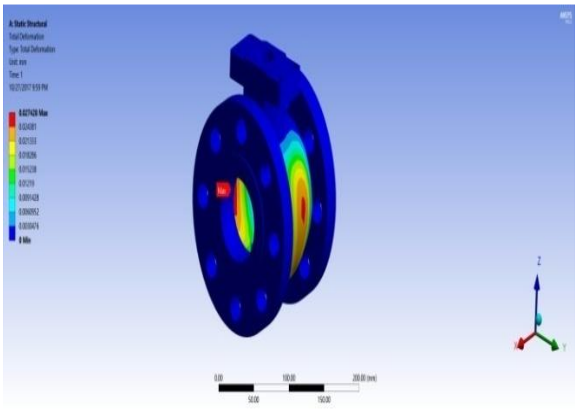

(7-b) - Total Deformation of New valve body

Figure 7:- EquivalentStress & Total Deformation Results in ANSYS of new valve body

Maximum Stress of valve body is 136.59 Mpa as shown in figure. In this case maximum stress is 136.59 MPa< 250 Mpa so design is safe. Maximum deformation of valve body is 0.0264 mm as shown in fig. (7-a) &(7-b).

IX. RESULT VALIDATION OF FEA &ANALYTICAL METHOD

Table VII. Result summary of FEA & Analytical Method

Model	Stress			Percentage difference %
	Maximum Stress Value MPa		Yield Strength of Material MPa	
	FEA	Analytical		
Old	89.81	85.36	250	2.54
New	136.59	115.22	250	8.48

The stress results obtain from the FEA method analysis was compared with the analytical method. Table VII shows summary of result of analytical and FEA method as well as result variation and percentage difference between these two method.

X. EXPERIMENTATION

The flow rate of valve is depend on valve size and pressure drop of valve. For getting accurate flow rate pressure drop must be maintain from 0.1 to 1. In this case as pressure drop decreases then flow rate increases so pressure drop is inversely proportional to flow rate. Industrial flow meter/ Rota meter is used to calculate flow rate of water, liquid or gas. Flow rate also calculated by from formula.

In manual calculation we used formula [3]

$$Q = Cv \times (\sqrt{(Sg} \div \Delta p) \div 1.156)$$

Cv- Capacity index is depend upon valve size

Sg – Specific gravity kg/m^3

Δ P – Pressure Drop= Inlet Pressure (P_1) – Outlet Pressure (P_2)

In this case the specific gravity is change as per flowing material. Flow rate of water is indicated as Q_1 for this Sg of pure water is 1 kg/m^3,Flow Rate of fuel is indicated as Q_2 for this Sg of fuel is 0.893 kg/m^3, Flow Rate of LPG gas is indicated as Q_3 for thisSg of LPG gas is 0.51 kg/m^3.

Calculation of flow rate of valve at 60^0& 90^{0}opening is as given in table VI & VII:-

Table VIII: - Old valve Flow Rate Calculation

Flow Rate Q m^3/hr	**Pressure drop ΔP**				
	0.1	**0.2**	**0.3**	**0.4**	**0.5**
Q_1	298.44	149.22	99.48	74.61	59.68
Q_2	282.02	141.01	94.00	70.50	56.40
Q_3	213.13	106.56	71.04	53.28	42.62
Flow Rate Q m^3/hr	**Pressure drop ΔP**				
	0.6	**0.7**	**0.8**	**0.9**	**1**
Q_1	49.74	42.63	37.30	33.16	29.84
Q_2	47.00	40.28	35.25	31.33	28.20
Q_3	35.52	30.44	26.64	23.68	21.31

Table IX. - New Valve Flow Rate Calculation

Flow Rate Q m^3/hr	Pressure drop ∆P				
	0.1	**0.2**	**0.3**	**0.4**	**0.5**
Q_1	139.51	98.65	80.54	69.75	62.39
Q_2	416.90	208.4	138.96	104.2	83.38
Q_3	315.66	157.5	105.02	78.76	63.01
Flow Rate Q m^3/hr	**Pressure drop ∆P**				
	0.6	**0.7**	**0.8**	**0.9**	**1**
Q_1	56.95	52.73	49.32	46.50	44.11
Q_2	69.48	59.55	52.11	46.32	41.69
Q_3	52.51	45.00	39.38	35.00	31.50

XI. CONCLUSION

After CFD analysis new valve body has internal pressure 5MPa. After simulation, the Maximum stress of 136.59 Mpa of new valve body is observed at 22^0c with maximum pressure of 10 mpa which is below the yield strength of the material. After experimentation & calculation Flow rate of water, fuel and LPG gas are 139.51m^3/hr,416.90m^3/hr& 315.06m^3/hr simultaneously. New modification in design overcomes the damage and friction between seat ring and plug.With successful increase in flow rate.

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