Analysis And Design Optimisation Of 200mm-150 Class Globe Valve Body By Using FEA And Validation By Using Experimental Stress Analysis Method

Ms. Pataskar Snehal Krishna, Prof. Mr. E.N.Aitavade,

Abstract-Globe valves are one of the oldest valve types used for throttling application for all sizes due to better controllability and range. This paper focuses on the design and analysis of 200mm-150 Class asymmetric globe valve with focuses on eliminating the problem faced by conventional globe mentioned above. Analysis of this globe valve takes place for high temperature applications. All the designs are based on BS and ASME standards.All the main components are designed and detailed drawing is produced. Modeling is produced on CATIA and the stress analysis is performed on ANSYS Software. Validation of FEA results is done by using Experimental stress analysis method. Now-a-days cost of the materials is very high, so there is need to minimize the cost. For this purpose, it is necessary to optimum use of man, machine and material. So that it is very important to reduce the weight of the globe valve body.

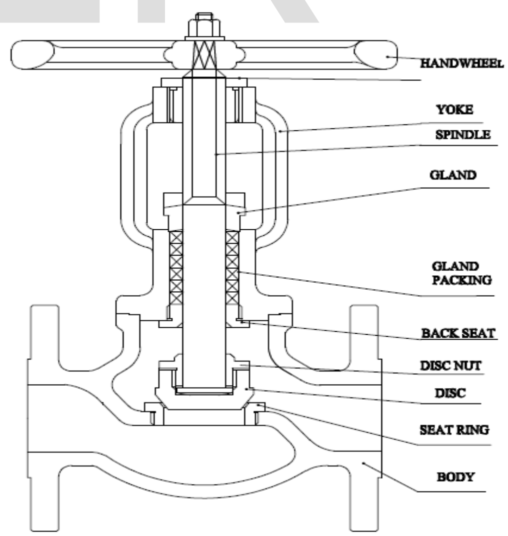
Index Terms-Finite Element Analysis,Weight Optimisation,American Petroleum institute (API) Standard,Thermal Analysis,Universal Testing Machine,Deformation plot,Stress analysis.

1 INTRODUCTION

Globe valves are closing-down valves in which the closure member is moved squarely on and off the seat. It is customary to refer to the closure member as a disc, irrespective of its shape. By this mode of disc travel, the seat opening varies in direct proportion to the travel of the disc. This proportional relationship between valve opening and disc travel is ideally suited for duties involving regulation of flow rate. In addition, the seating load of globe valves can be positively controlled by a screwed stem, and the disc moves with little or no friction onto the seat, depending on the design of seat and disc. The sealing capacity of these valves is therefore potentially high[15].

Pataskar Snehal Krishna,is a M.E candidate at the department of Mechanical Engg, Ashokrao Mane Group of Institutions, Vathar, Dist-Kolhapur, 416112, Maharashtra,
E-mail:snehal.pataskar@gmail.com
E.N.Aitvade ,is a Professor at the department of Mechanical Engg, Ashokrao Mane Group of Institutions, Vathar, Dist-Kolhapur, 416112, Maharashtra,
E-mail-enaait@yahoo.co.in

1.1 Main Components of Globe Valve



1.1.1 **Valve Body**

The Valve body is the first boundary of a pressure Valve. He serves as the main element of valve assembly because it is the framework that holds all the parts together. The Valve-body ends are designed to connect the Valve to the piping or equipment nozzle by different types of end connections, such as butt or socket welded, threaded or flanged.

1.1.2 **Valve Bonnet**

A Bonnet acts as a cover on the Valve body, is cast or forged of the same material as the body. It is commonly connected to the body by a threaded, bolted, or welded joint. During manufacture of the Valve, the internal components, such as stem, disk and actuator, are put into the body and then the Bonnet is attached to hold all parts together inside. The bonnet of a control valve is that part of the body assembly through which the valve plug stem or rotary shaft moves. On globe or angle bodies, it is the pressure retaining component for one end of the valve body. The bonnet normally provides a means of mounting the actuator to the body and houses the packing box

1.1.3 **Valve Disc**

The disc is the part which allows, throttles, or stops flow, depending on its position. In the case of a plug or a Ball Valve, the disc is called plug or a ball. The disc is the third most important primary pressure boundary. With the Valve closed, full system pressure is applied across the disk, and for this reason, the disc is a pressure related component

1.1.4Valve Seat

A Valve may have one or more seats. In the case of a globe or a swing-Check Valve, there is usually one seat, which forms a seal with the disc to stop the flow. In the case of a Gate Valve, there are two seats; one on the upstream side and the other on the downstream side. A Gate Valve disc has two seating surfaces that come in contact with the Valve seats to form a seal for stopping the flow. The seat ensure the seating surface for the disk. For a good sealing, a fine surface finish from the seating area is necessary.

1.1.5 **Valve Stem**

Hand-operated Valves are usually equipped with a handwheel attached to the Valve's stem or Yoke nut which is rotated clockwise or counter clockwise to close or open a Valve. Globe and Gate Valves are opened and closed in this way.

1.1.6 **Valve Yoke**

A Yoke connects the Valve body or Bonnet with the actuating mechanism. The top of the Yoke holding a Yoke nut, stem nut, or Yoke bushing and the Valve stem passes through it. A Yoke usually has openings to allow access to the stuffing box, actuator links, etc.Structurally, a Yoke must be strong enough to withstand forces, moments, and torque developed by the actuator.

2 SPECIFICATIONS OF 200MM-150 CLASS GLOBE VALVE BODY

2.1Material of Globe Valve Body

The material used for the valve body and seat ring and then for the base material are as follows.The material used is ASTM A216 grade WCB is a type of ASTM A216 cast steel.**Cast Carbon Steel ASTM A216 Grade WCC** Temp. range = –20 to 800°F (–29 to 427°C).Composition (Percent): C 0.25 max, Mn 1.2 max,P 0.04 max, S 0.045 max, Si 0.6 max. Material properties are as follows shows in table 1[15].

TABLE 1
Material Properties of ASTM A216 Grade WCC

S/NO	MATERIAL PROPERTIES	RANGES
1	Young's Modulus	210 Gpa
2	Poisson Ratio	0.29
3	Specific heat capacity	450 J/kg-K
4	Thermal Expansion	12 $\mu m/m$-K
5	Tensile Strength(UTS)	570Mpa
6	Tensile Strength(proof)	290 Mpa
7	Density	7.8 g/cm^3
8	Strength to Weight Ratio	73 kN-m/kg
9	Specific heat capacity	450 J/kg-K
10	Modulus of Resilience	200 kJ/m^3

Selection of material is carried out according to working temperature,working pressure,type of fluid and standard temperature-pressure rating as specified in ASME B 16.34 shown in table 2.

TABLE 2
SELECTION OF MATERIAL

Sr.No.	Part Name	Material
1	Body	ASTM A216 Gr.WCB/CF8/CF8M
2	Bonnet	
3	Seat ring	AISI 304/AISI 316/ AISI 410/A20/BRONZE
4	Disc	
5	Spindle	
6	Back Seat	
7	Gland Packing	
8	Gland	AISI 304/AISI 316/AISI 410
9	Handwheel	ASTM A216 Gr.WCB
10	Bonnet Stud	ASTM A193 Gr.B7
11	Bonnet Nut	ASTM A194 Gr.2H

2.2 Selection of Dimensions from Standards

Cast Carbon Steel (ASTM A216 Grade WCC)—WCC is the most popular steel material used for valve bodies in moderate services such as air,saturated or superheated steam, noncorrosive liquids and gases. WCC is not used above 800⁰F (427⁰C) as the carbon rich phase might be converted to graphite. It can be welded without heat treatment unless nominal thickness exceeds 1-1/4 inches (32 mm).

1)Pressure rating - ASME B 16.34
2) Valve body minimum wall thickness - ASME B16.34
3) Face to face dimensions for flanged welded valves – ASME B 16.25
4) Testing standards – API 598
5) Dimensions of bonnet and stem – BS 1873
6) Flanged weld design – BS 1873
7) Pipe line standard - ASME 16.1
8) Required machining allowance - ISO 8062

3 Finite Element Analysis

Simple mathematical model can be solved analytically, but more complex model requires use of numerical methods. FEA is one of the numerical methods used to solve complex mathematical problem. The entire solution domain must be discretized into simply shaped sub domain called as elements. ANSYS software is used for the analysis of the valve body, which is based on the FEA method. In ANSYS it's very difficult to model the part with parametric modeling as compared with the available modeling software such as CATIA and Pro-E. To create a 3D model of valve body with all intricate geometric details CATIA software is used. The created 3D model of valve body is as shown in fig.1

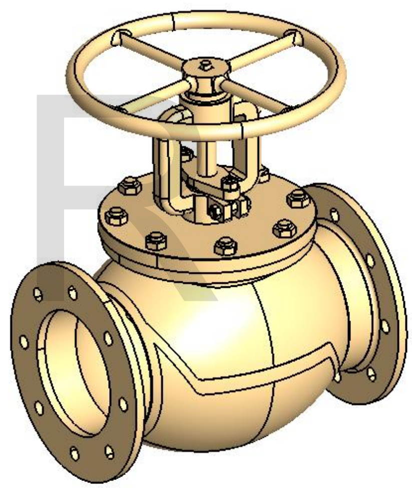


Fig.1 Globe Valve Model using CATIA

In this project, finite element analysis was carried out using the FEA software ANSYS. The primary unknowns in this structural analysis are displacements and other quantities, such as strains, stresses, and reaction forces, are then derived from the nodal displacements[8],[3].

3.1Thermal Analysis

Thermal analysis is performed to find out the temperature distribution over the complete body of an object due to an internal heat source and all three form of heat transfer are considered while analyzing the module. Conduction, Convection and radiation are the three modes of heat transfer that are considered while performing thermal analysis of the globe valve. We need to import the structural model for thermal analysis and connections are to be made for structural model shown in fig.2[2].

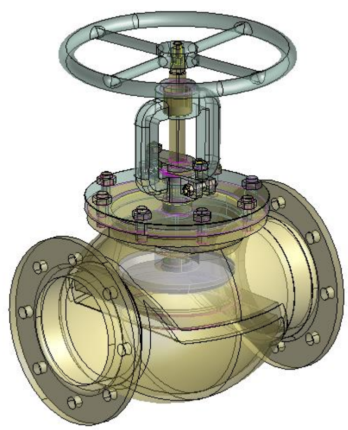


Fig.2 Structural model of globe valve

While building FEA model all components are modelled as solid model and Element type 185 is used for meshing them. We have performed FEA Analysis on glove valve solid shell element (Solid 185) is used for modeling[8],[13]. So that bending forces are accounted for and we get both the surfaces for the contacts.Deformation results for old model when applying the boundary conditions of 22 Bar and room temperature are shown in fig.3 and fig.4

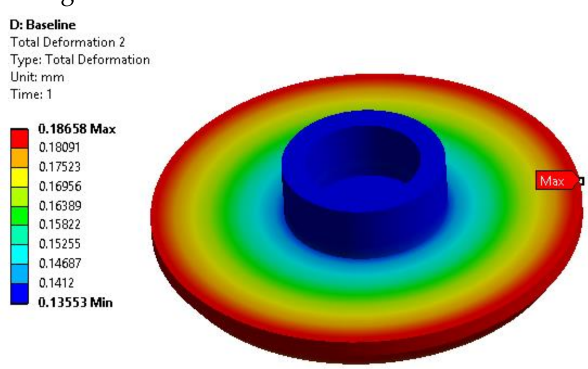


Fig. 3 Total Deformation plot and Maximum deformation of disc for 22bar and room temp in ANSYS V9

Maximum deformation plotted at disc is 0.187mm.

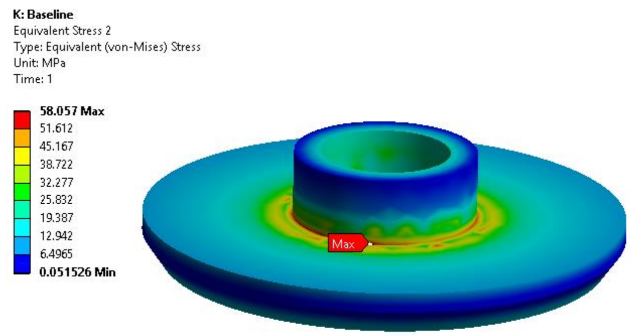


Fig.4 Von Mises stress plot at the disc (MPa)

Maximum von mises stress plot observed at the disc is 58.06 MPa when it is subjected to 22bar and room temp in ANSYS V9.

When disc is subjected to pressure of 12 bar and heated upto and 250ºc,then deformation and stress plots are shown in fig.5 and fig.6.

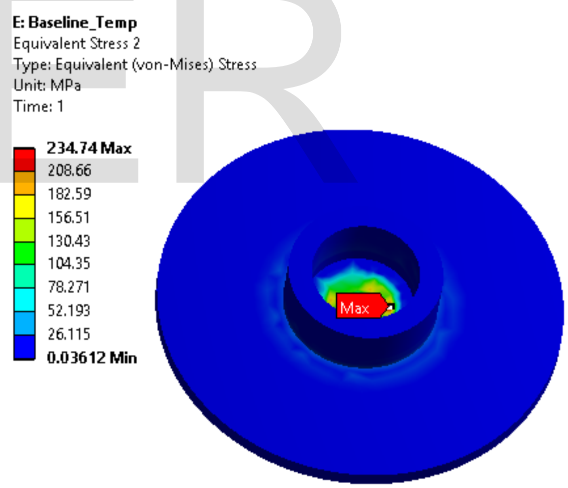


Fig.5 Von Mises stress plot at the disc (MPa)

Maximum von mises stress plot observed at the disc is 234.7MPa.

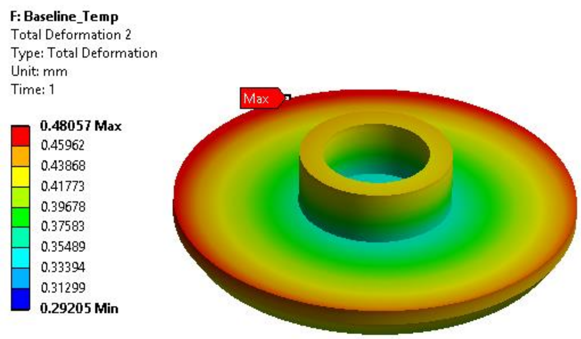
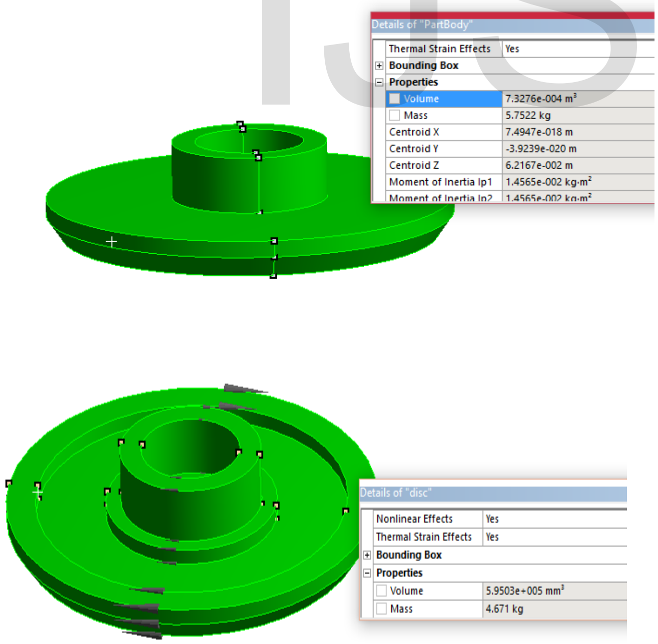


Fig.6 Total Deformation plot and Maximum Deformation of disc for 12 bar and 250ºc in ANSYS V9

Maximum deformation plotted at disc is 0.48mm.From the analysis results we can clearly see that maximum stress and deformation region on the analysis plots is seating disc. It weighs around 5.75 kg and which has a lot of scope for



weight reduction as shown in fig.7

Fig.7 Comparison of old and optimized globe valve disc

Globe valve seating can experience fluctuating stresses which may cause fatigue failure in it. So we will consider the iron endurance limit as the acceptance criteria for the stress acceptance limit. Considering the endurance limit of the steel as 120 MPa and steel strength degradation to 60 % of the original strength due to temperature up to 500 ºC we have steel endurance strength at high temperatures as 72 MPa. Considering factor of safety for the application of steam valve as 3 because it is significant application to human safety of the people working around the valve. We have acceptance stress limit at the seating as 24 MPa. We have a lot of scope to remove the material of the seating without losing the sealing it provides when lowered. Different iterations are performed for removing material from the valve seating which has inner diameter of material removal region as 97 mm and outer diameter of the ring cut is 177 mm. Depth of the ring is increased step by step from 1 mm to 8 mm in 8 iterations performed and stresses at the different iterations recorded. At the iteration 8 stresses are close to the acceptance limit so no further iterations are performed[6],[12],[4]. Disc weight has been reduced from 5.75 kg to 4.67 kg which is approximately 19 % weight reduction when compared with the original valve seating design.Final deformation and stress plot at the optimized disc when applying the boundary conditions of room temperature,22 bar are shown in fig.8 and fig.9

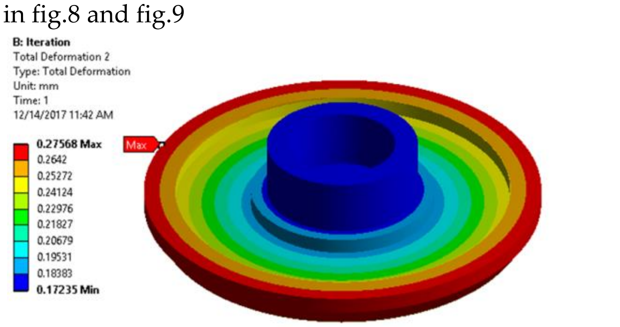


Fig.8 Total Deformation plot and Maximum deformation of optimized disc for 22bar and room temp in ANSYS V9

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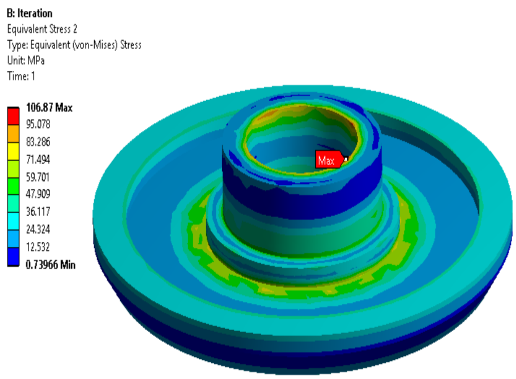

Fig.9 Von Mises stress plot at the disc (MPa)

Maximum von mises stress plot observed at the optimized disc is 106.87 MPa when it is subjected to 22bar and room temp in ANSYS V9.

When optimized disc is subjected to pressure of 12 bar and heated upto and 250ºc,then deformation and stress plots are shown in fig.10 and fig.11

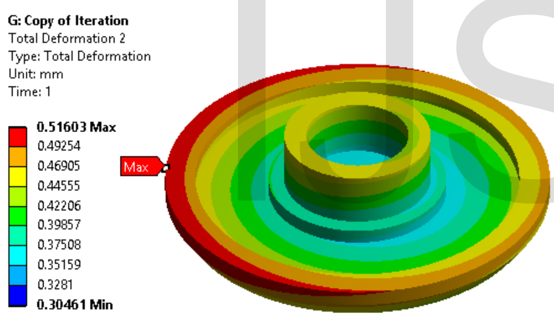

Fig.10 Total Deformation plot and Maximum deformation of optimized disc for 12bar and250ºc in ANSYS V9

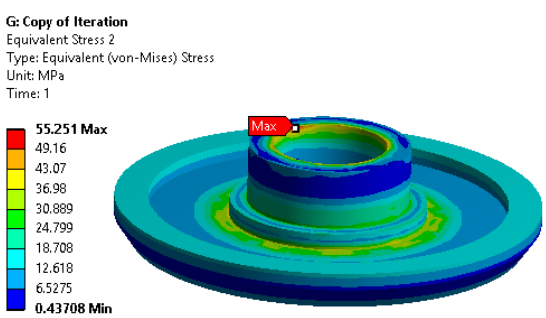

Fig.11 Von Mises stress plot at the disc (MPa)

Maximum von mises stress plot observed at the disc is 55.25MPa.

4 Hydraulic Leakage Test

As per API standard, globe valve with old and optimized disc is tested hydraulically under the pressure of 22 bar. Results of leakage test is as shown in given table 3.

TABLE 3

HYDRAULIC LEAKAGE TEST RESULTS

Sr.No.	Test Description	Test Duration in sec	Remark
1	Shell Test	120	No leakage
2	Backseat Test	60	
3	High Pressure Test	120	

5. Experimental Validation by using Experimental Stress Analysis Method

The objective of 'Experimental stress analysis' is to find stress conditions in a structural element or machine part subjected to some specified loading either by observation of physical changes brought in it or by measurement mode on model[7],[14]. For validation with FEA results, the best method we implement is universal testing machine with star testing system. Old and optimized disc are heated in oven to maintain the temp of 250ºc.Both discs are alternatively mounted on middle crosshead of universal testing machine. For measuring the temperature of disc, RTD is connected to disc. For measuring the deformation of disc, dial indicator is mounted on disc. Results are obtained by applying load of 22bar and 12bar. Experimental set up is as given in fig.12

Fig12.Experimental Set Up

6 Results and Discussion

6.1Results

With the help of star testing software which is connected to universal testing machine,following maximum stress and deformation results are plotted.

TABLE 4

MAXIMUM STRESS AND DEFORMATION PLOT AT OLD DISC

	Unoptimised Disc	
	Atm. Temp At 22 bar	250^0c temp At 12 bar
Time(sec)	16.6	14.9
Displacement(mm)	0.21	0.52
Load(N)	25598	14063
Stress(Mpa)	62.93	239.4

TABLE 4

Maximum Stress and deformation plot at optimised disc

	Optimised Disc	
	Atm. Temp At 22 bar	250^0c temp At 12 bar
Time(sec)	17.6	16.4
Displacement(mm)	0.31	0.65
Load(N)	25872	14406
Stress(Mpa)	111.1	57.01

6.2 Validation of FEA results by experimentally

TABLE 6

COMPARISON OF MAXIMUM STRESS PLOT OF OLD AND OPTIMIZED DISC

Stress (Mpa)	Unptimised Disc	
	Atm. Temp At 22 bar	250^0c temp At 12 bar
FEA results	58.06	234.74
Experimental results	62.93	239.4
	Optimised Disc	
FEA results	106.87	55.25
Experimental results	111.1	57.01

Deformation of disc at three different locations on disc is found out for load of 22bar and 12bar by using dial indicator..This experimental results are validated with FEA results as given in table 7.

TABLE 7

DEFORMATION OF DISC

Deformation of Disc(mm) ⇨	Unoptimised Disc			
	Atm. Temp At 22 bar		250^0c temp At 12 bar	
(Distance of Dial Indicator from centre of disc) ⇩	FEA	TES-TING	FEA	TES-TING
97mm	0.19	0.21	0.48	0.52
86.2mm	0.18	0.20	0.45	0.49
75.4mm	0.17	0.19	0.43	0.47

Optimised Disc	Atm Temp. At 22 bar		250^0c temp At 12 bar	
(Distance of Dial Indicator from centre of disc)	FEA	TES-TING	FEA	TES-TING
97mm	0.27	0.31	0.51	0.65
86.2mm	0.26	0.30	0.49	0.63
75.4mm	0.25	0.29	0.46	0.59

6.3 Discussion

1. The stress plot at the old disc is in increasing order when it is heated from room temperature to high temperature.So,it is required to minimize the maximum stress.In order to overcome the stress effect,best result is to optimize the disc.Because of weight optimization,stress effect is decreasing gradually when disc is heated from low temp.to high temp.It is proven experimentally.
2. From above deformation table, It has been clearly seen that ,because of weight optimization of disc, deformation of modified disc is increased as compared to old disc. So there is a chance of leakage of disc due to increase in deformation. But,during hydraulic leakage test, it is prove that leakage of modified disc is not going to happen under 22bar pressure. Hence it seems clearly that as far as deformation increases, there is no any leakage occur while testing of modified disc.

Therefore ,it is helpful by using weight optimization, production rate is increased, manufacturing cost is also reduced. It helps to increase the productivity as well.

7 CONCLUSION

1. Stresses in the valve and seating are well within the acceptance criteria of 24 MPa.
2. New design of disc whose weight has been reduced from 5.75 kg to 4.67 kg which is approximately 19 % weight reduction when compared with the original valve seating design and analysis is performed to prove its safety.
3. Stresses in the new valve seating design are below acceptance limit of 24 MPa after applying factor of safety 3 for the design.

8 ACKNOWLEDGEMENT

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