Design And Analysis of A Bellow Sealed Gate Valve

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Abstract— Valves have its own importance in all type of industries and used for regulating the fluid flow and direction. Design of valves is a complicated task and it demands the different types of designs for the different type of applications and primarily it depends upon the media of flow. Due to regular operation the trim parts of the valve are going to wear out. This worn out surfaces may form a gap between the mating surfaces and cause the fluid leakage. To prevent these types of leakages, a bellow is added to the valve and this bellow prevents the media leakages even after formation of worn out surfaces. The work is focused on designing of bellows and some additional supporting parts to establish a bellow sealed gate valve. The API-598 testing standards are adopted for testing. A valve assembly is modeled and numerical analysis is carried out to validate the results. The designed model is checked with the operational parameters like pressure and temperature in a SolidWorks Simulation software tool and confirmed that all the results fall below the Von-mises stresses and has concluded that designed models are safe.

Keywords—fluid media leakage;gate valve; bellow; stress analysis.

I. INTRODUCTION

Definition: A valve is a device adopted for isolating, controlling and regulating the flow of fluids.

It is difficult to find an industry everywhere throughout the world in which valves don't exists. Valves plays their importance all over; from atomic subs to surface vessels, from high-temperature for cryogenic applications, from tall structures to single story structures, from space tests to remote ocean investigations, from planes to vehicles, from force plants to refineries, and processors of each sort possible. Valves are of essential significance and principally embraced in channeling transportation frameworks on account of their capacity and it is noteworthy that a correct type of valve is embraced for the subroutine, and must be made of the right material for the process fluid.

A Gate Valve is a linear motion valve used to begin or stop the liquid stream; on the other hand, it doesn't control or throttle stream. The name gate is gotten from the presence of the wedge in the fluid flow stream. Figure 1 delineates the typical model of a Gate Valve.

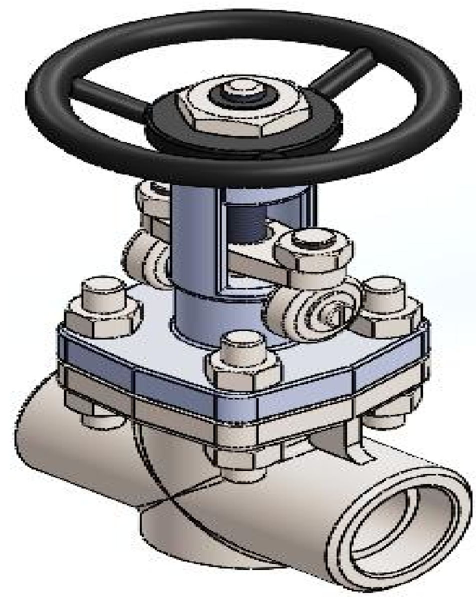


Figure 1

The wedge or gate of a Gate Valve is totally raised up and made open from the stream when the valve is completely open. This trademark offers practically zero imperviousness to the stream when valve is open. In any case, there will be a little pressure drop because of sudden change in cross area.

At the point when the valve is completely shut, a wedge to seat ring contact surface happens for 360°, and great fixing is given. With the correct mating of a plate to the seat ring, next to no or no leakage happens over the circle when the Gate Valve is closed.

On opening the Gate Valve, the stream way is expanded in an exceedingly nonlinear way regarding rate of opening. This implies that stream rate does not change equally with stem travel. Additionally, a partially open wedge has a tendency to vibrate from the fluid flow. Most of the flow change occurs near shutoff with a relatively high fluid velocity causing disk and seat wear and eventual leakage if used to regulate flow. For these reasons, Gate Valves are not used to regulate or throttle flow.

Problem description: Valves used for piping systems, nuclear power plants, flow channels, boilers and in many industries. To control flow are subjected to various types of loads and stresses. It becomes necessary to design the valve to sustain such complex loads. But designing the valve for the complex load conditions doesn't mean a good design; the designed valve must be of leak proof and good life characteristics.

In actual practical applications the valve trim are under continuous wear, friction, impact thermal loads. These wear of the trim parts may cause gap between the mating surfaces and makes the passage for fluid leakages. This wear may occur after several use of valve and leads to replace the affected parts and even whole valve sometimes. This work is mainly focuses to prevent the leakages from the valves. Work is carried out on 1 inch, #300 class, and forged Gate Valve.

I. LITERATURE SURVEY

Dr. K.H. Jatkar and Sunil S. Dhanwe [1] published a journal entitled “Finite Element Analysis of Gate Valve " and the paper embodies on the Finite component examination of Gate Valve. A model Normal Gate Valve is produced and each essential part are examined. Stress investigation is finished by FEM and approval is upheld by established hypothesis of mechanics.

Brijeshkumar. M. Patel [2], a PG understudy from S.P.C.E. Visnagar, India has taken a shot at metal Bellows utilized as a part of funneling commercial ventures and distributed his work entitled " Design, Manufacturing and Analysis of Metal Expansion Bellows " which unmistakably tells The adaptable component of a development joints comprising of one or more convolutions and the end digression with the proportion of length of the Bellows to the width of the Bellows must be less or equivalent to three without any than five handles. Most mechanical channeling framework frequently endure unreasonable misshaping, effects, removal, weariness, heat extension, web blanket, vibration, and different reasons are in charge of the disappointment. In his work, he has concentrated on the disappointment of Bellows made of SS 304 has been dissected. Over pressure, effects and Vibration of steam are the dependable reasons for the Bellow disappointment. After complete perception he has found that the wrong outline information accepted at the season of Bellows assembling are made Bellows to fall flat in a short administration time. Taking into account the above said perception and investigation, the Bellows are re-planning by utilizing EJMA code. In his work another strategy has been proposed for assembling of the metal Bellows and essential parameters, for example, starting length of tubes, interior weight, hub sustaining, speed, mechanical properties, sorts of material utilized are likewise mulled over. In this work a limited component examination of Bellows proposed in his paper for the approval of the product results and EJMA configuration computed results. At long last the acceptance of aftereffects of EJMA configuration ascertained worth and FEA quality demonstrates a decent understanding.

S.W. Lee [3] published a paper titled "Study on the forming parameters of the metal Bellows" the paper information's on the assembling procedure of the metal Bellows comprises of shaping procedures to be specific: profound drawing, pressing, tube-protruding and collapsing. The tube-swelling and collapsing procedures are basically vital in light of the fact that the nature of the metal Bellows is incredibly affected by the framing states of these procedures. Additionally, the last convolution state of the Bellows is resolved soon after the spring back stage and from the element mull over, the most imperative element affecting the last state of convolution of the metal Bellows is figured out. The consequences of his study could be utilized as a premise of outlining another kind of the metal Bellows.

C.Becht IV has proposed a new design approach for Bellows under cyclic loading in his work entitled “Fatigue of Bellows, a new design approach” consideration of fatigue is generally an important aspect of design of metallic Bellows. These parts are subjected to removal stacking which every now and again brings about cyclic strains will past as far as possible for the material [4].

II. CONSTRUCTION OF A GATE VALVE

Gate Valves comprises of three fundamental parts: body, Bonnet, and trim. The body is for the most part associated with other moving parts by method for flanged, screwed or welded associations. The Bonnet, which containing the moving parts is appended to the body more often than not with jolts to allow support and welding associations if needed. The Valve trim consists of the stem, the gate, the disc or wedge and the seat rings. Figure 2 shows the detailed section view of normal gate valve.

Figure 2

Valve Body: Valve body, also called as a valve shell, is considered as a primary pressure element in a valve structure, because the media flowing through the pipeline directly makes a contact with the valve body and the pressure created by the media directly strikes on the surface of the body.

Valve Bonnet: Bonnet is a secondary pressure element in a valve assembly and it is considered as a cover for the opening in the body. Bonnet gives adequate support to trim parts like stem, yoke sleeve and for an actuator.

Disk or wedge of a Gate Valve: Wedge is the part which manages or stops the stream of liquid, contingent upon its position. The Wedge is the third most imperative essential pressure limit after the body and bonnet. With the valve completely shut, a full framework weight is constrained on the plate surface on which liquid will be in contact.

Stem of a Gate Valve: The stem, which connects the hand wheel and disk with each other, is responsible for the proper positioning of the disk.

Valve Yoke: A Yoke interfaces the Valve body or Bonnet with the stem and actuating system. A Yoke more often than not has openings to permit access to the stuffing box, actuator joins, and so on.. Basically, a Yoke must be sufficiently strong enough to withstand forces, moments, and torque developed by the actuator.

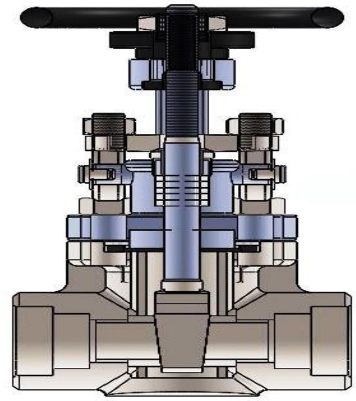


Figure 3

III. BELLOW DESIGN

The Bellow is the flexible element of an expansion joint consisting of one or more convolutions or corrugalations and the end tangents. This element is designed to absorb thermal movements and mechanical movements. The number of convolutions in a Bellow is having a direct relationship to the amount of thermal or mechanical movement and the force necessary to achieve desired deflection, a typical model of bellow is shown in figure 3.

The system pressure and deflection causes the significant stresses in a Bellows. Regularly the deflection stresses are higher than the pressure stresses.The pressure stresses incorporate circumferential anxiety in the Bellows digression and the convolutions. Expansion Joints Manufacturers Association (EJMA) characterizes the Bellows digression membrane stress because of pressure.

There are also meridional pressure stresses that are evaluated in the design of a Bellows. The Bellows meridional membrane stress due to pressure is designated in the EJMA calculations. The other meridional stress that is evaluated in EJMA is the Bellows meridional bending stress due to pressure. If these meridional stresses are exceeded, the convolution sidewall will be overstressed and this will lead to Bellows failure.

EJMA uses a “Combined Stresses” technique to evaluate the approximate cycle life of a Bellows. The stresses involved are recorded in EJMA. A cycle is defined as one complete movement, at pressure and temperature, from the initial position of the Bellows, to the operating position, and back to the initial position. Factors that affect the fatigue life of a Bellows are, operating pressure, operating temperature, Bellows material, movement per convolution, Bellows thickness, convolution pitch, convolution height and shape, and Bellows heat treatment. Based on the evaluation techniques in EJMA, it is possible to predict the cycle life of a Bellows rather than cycling to failure.

Bellow Failure Modes: There are three primary types of failure that are of concern with respect to interna1 pressure loads. The first is simply burst failure due to excessive circumferential membrane stress. This is the failure mode for which reinforcing rings are used. It results when the circumferential membrane stress exceeds the tensile strength of the material.

The second type of failure is a limit load type of failure resulting from the formation of plastic hinges in the roots, sidewalls and crowns of the Bellows. This failure mode is called as in-plane squirm.

The third type of failure is called column squirm. It is a buckling failure of the Bellows due to internal pressure.

How a Bellows Works? : A Bellows is a flexible seal. The convoluted portion of an expansion joint is designed to flex when thermal movements occur. The number of convolutions depends upon the amount of movement the Bellows must accommodate or the force that must be used to accomplish this deflection. The convoluted element must be strong enough circumferentially to withstand the internal pressure of the system, yet responsive enough to flex. The longitudinal load (pressure thrust) must then be absorbed by some other type of device. Pressure thrust can be calculated by multiplying the effective area by the working pressure.

Multiple Ply Construction: The essential measure of metal to contain pressure can be accomplished with a solitary employ of Bellows material or different handles of material of diminished thickness. A Bellows of different utilize development regularly has a lower spring rate than a solitary employ Bellows for the same administration. Slim material encounters less strain than a thick material for the same avoidance. That implies a different employ Bellows may be shorter and it may have a higher cycle life than a solitary handle Bellows for the same application.

Design Limits:

- Diameters up to 9" are possible for valves.

- The ratio, I.D. /O.D. should be 0.6 or greater. For an efficient Bellows, 0.65 is the optimum value. Higher values can be supplied where maximum effective area or small space are required, but at the expense of the Bellows stroke.

- Wall thickness, outer groove widths, and inner groove widths, should conform to the values

For the current work,

- The stem is of 11 mm diameter hence we need to choose the ID of the Bellow which is larger than the stem diameter.

- Wedge height is 39 mm, for fully throttle the valve wedge the stem has to displace 39 mm in a linear direction so the Bellow has to select which gives minimum linear displacement of 39mm with the standard allowable condition I.e., only 50% of the convolution displacing is allowed either in expansion or compression. Hence the numbers of convolutions assumed are 75.

- The designed Bellow including top and bottom collars, total height is added to the stem length and the stem is redesigned with the same diameter by adding only the height.

- Cylinder is chosen depending upon the Bellow height and outer diameter, a sufficient gap is provided in between the ID of cylinder to OD of the Bellow to avoid the contact between them.

- Cylinder flanges are designed according to the body and bonnet flange thickness and the OD of cylinder. Threads are made to lock/mate in between the flanges and cylinder. Welding is done in between the body flange and cylinder bottom flange and similarly bonnet flange and cylinder top flange.

Table 1 provides the design data and dimensional information regarding on Bellow.

Table 1

Bellow material	Titanium stabilized Austenitic Stainless steel / 1.4571 / 361Ti
Bellow ID	D_i=16.8mm
Bellow OD	D_o= 24mm
Bellows Mean Diameter	D_m=21mm
Bellow convolution pitch	q= 2.3mm

Bellow convolution height	w= 3.6mm
Number of plies	n= 2
Number of convolutions	N=75
Individual ply thickness	t=0.15mm
Equivalent axial moment	e= 0.575mm
Material thickness factor	t_p=0.1342

EJMA Equations for Bellows

Most Bellows today are designed using the equations provided in the Standards of the Expansion Joint Manufacturers Association.

The Bellows circumferential stress due to internal pressure, S2 is

$$S_2 = (PD_m / 2nt_p)\ [1 / (0.571 - 2(w/q))]$$

The Bellows meridional membrane stress due to internal pressure, S3 is

$$S_3 = Pw / 2nt_p$$

The Bellows meridional bending stress due to internal pressure, S4 is:

$$S_4 = (P/2n)\ (w / t_p)^2\ C_p$$

The Bellows meridional membrane stress due to deflection, S5 is:

$$S_5 = Etp2e / 2w^3 c_f$$

The meridional membrane stress due to deflection is the force required to deflect the Bellows divided by the metal area based on the mean diameter and wall thickness of the Bellows. Because this stress is due to displacement, it would typically be considered to be a secondary stress

The Bellows meridional bending stress due to deflection, S6 is:

$$S6 = 5Etpe / 3w^2 c_d$$

Axial force to deflect a convolution a distance, F is

$$F = S_5\ \pi\ D_m\ t_p$$

Bellows theoretical elastic axial stiffness per convolution, f_{iu} is

$$f_{iu} = F/e$$

Bellow stress calculations

Applying the specified and required values and data from the Table 1 and into the set of equations, we get

- The Bellows circumferential stress due to internal pressure, S2= 94.55 MPa
- The Bellows meridional membrane stress due to internal pressure, S3= 67 MPa
- The Bellows meridional bending stress due to internal pressure, S4=1349.3 MPa
- The Bellows meridional membrane stress due to deflection, S5= 15.85 MPa
- The Bellows meridional bending stress due to deflection, S6= 1323.13 MPa
- Axial force to deflect a convolution a distance, F= 140 N
- Bellows theoretical elastic axial stiffness per convolution, f_{iu}= 528.38 N/mm

The ratio of the bending stress to membrane stress is approximately equals to the ratio of Bellows convolution height, w, to the ply thickness, t. Because metallic Bellows are thin walled shells, this ratio is relatively large, making the meridional bending stress much larger than the meridional membrane stress. Since the stress criteria are relative to the sum of these two components, meridional membrane stress is generally relatively insignificant in Bellows design.

The obtained stress valves are well below the yield strength value of the Bellow material under the specified pressure and temperature conditions. The stresses S4 and S6 are relatively large to other stresses and these stresses are justified and acceptable as above said.

Results are validated by with comparing the present study with the work done by Brijeshkumar. M. Patel, a PG student from S.P.C.E. Visanagar, India. On his publication entitled

"Design, Manufacturing and Analysis of Metal Expansion Bellows"

IV. BELLOW SEALED GATE VALVE

The normal model of a gate valve is shown in Figure 1 and Figure 2 and it is redesigned to make a Bellow sealed gate valve by adding few additional parts like bellow, cylinder and flanges as shown in figure 4. Two gaskets are additionally added at top and bottom faces of the top collar side of the Bellow. This gasket is added here to avoid the metal to metal surface leakages.

The body flange and bonnet flange of a Bellow sealed valve is made round compared to normal gate valve as shown in Figure 1 and according to the flange dimensions the cylinder flanges are also designed. The cylinder chosen here is of the same material as of wedge i.e., AISI-316 and analyzed with the practical condition to check the sustainability.

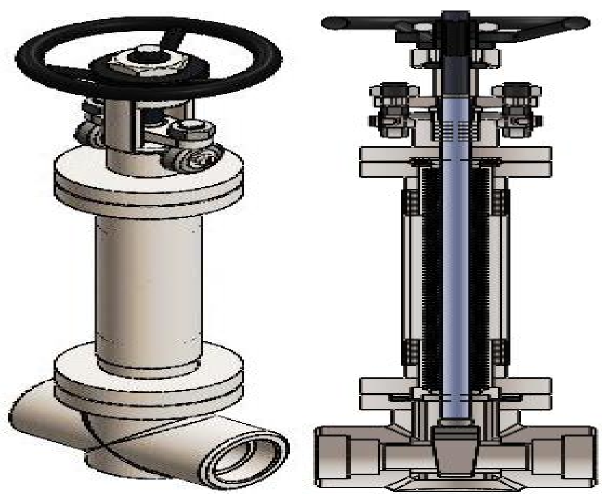


Figure 4

Advantages of the bellow sealed valve over the normal valve.

- It prevents leakage and the leakage is almost zero.
- Additions of impurities are eliminated.

Disadvantages over the normal valves

- Complex and sensitive design
- Rework is not possible for some parts
- Large size compared to normal valves

Design of valve parts is done as per the standards available and must to be satisfied the values and criteria of design. It includes pressure ratings, material specification, test methods and we need to satisfy all the conditions to obtain a reliable and optimum design model. The lists of standards which are used in valve design are mentioned in the previous chapter.

Economics of using a bellow sealed gate valve over a normal gate valve:

Let us assume a clearance or gap of 1mm for the estimation of a leakage. Consider a fluid is flowing through the valve and cost of the fluid is Rupees 200 per liter. Fluid will be continuously leaking at a rate of 0.25litre per hour.

Now, there will be a leakage of one liter fluid for every working of four hours, at the normal condition considering 8 working hours in a day. So there will be a loss of 2 liter fluid and that costs Rupees 400 per day. Consider a number of working day in a year are 250 days, so now the loss will be of 500 litres which costs Rupees 1,00,000/-.

The above said media loss is for an individual valve, if the numbers of valves are more, the loss will be more.

Adoption of Bellow sealed valve can reduce the leakage problems up to 99% and which saves the fluid and money

V. FEM ANALYSIS

A current design of 1 inch 300class forged valve is taken and it is tested at the standard test conditions, after confirming the designed model practical operating condition and to carry out a FEM analysis, task was to add the Bellows to the current model to prevent from valve leakages.

In addition to the current model, few more parts are designed to establish a Bellow sealed valve. The parts are namely Bellow, flange and stem.

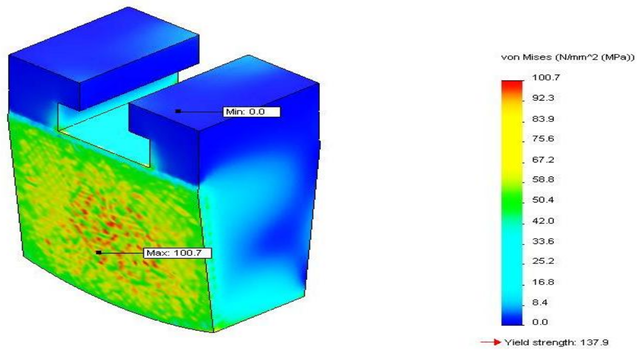
The standard testing conditions as per API-598 for the above designed valve are

Test pressure	Class - #300 valve
Body-Hyd	7.55 MPa
Seat-Hyd	5.5 MPa
Seat-Air	0.7 MPa

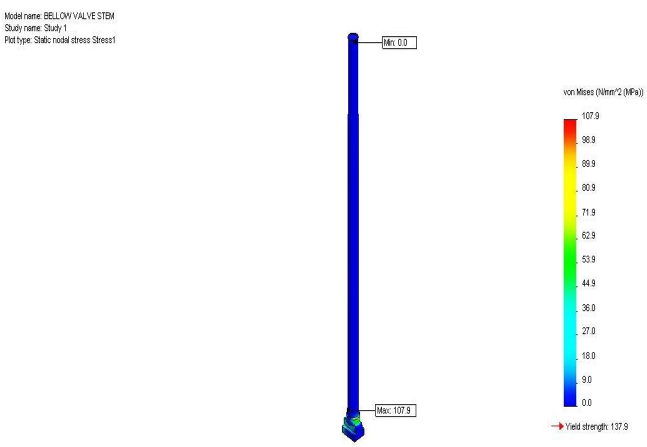
One test is enough to check the sustainability of the component at the test conditions for the given pressure loads, the higher test pressure values are at hydraulic test for body at 7.55MPa. Hence here in this work the test pressure for the valve is 10MPa and temperature load of 50° Celsius is taken.

The analysis is done in SolidWorks Simulation and results are plotted and compared with the theoretical calculations.

Simulation of wedge

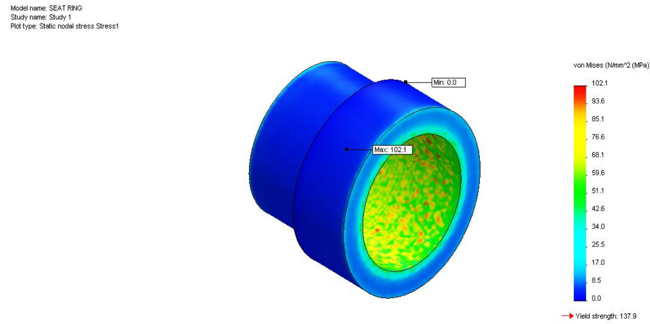


Simulation of valve stem

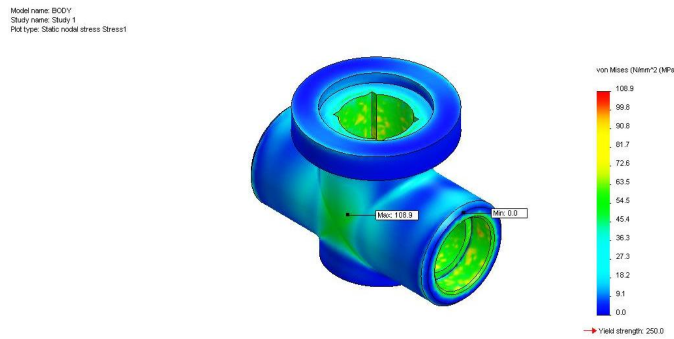


Simulation of Cylinder

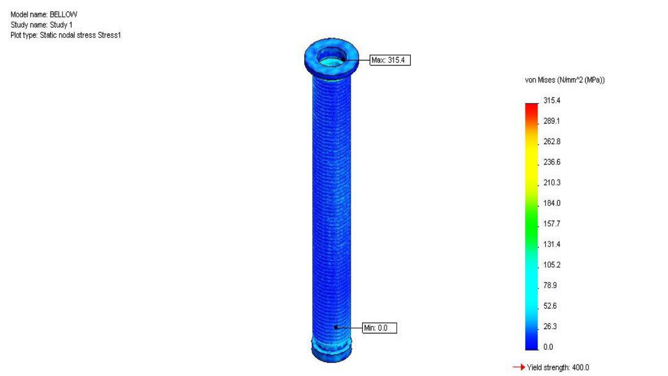
Simulation of seat ring



Simulation of body



Simulation of bellow



VI. CONCLUSION

- The results on Von-Mises stress obtained are compared with the yield strength of the material used for each component analyzed. Yield Strength provided is according to the design and material Standards. The stresses obtained are within the yield strength limits.

- The total deformation and equivalent strain occurred due to the applied pressure and temperatures are very small and negligible in all the components analyzed.

- In bellow design, few stresses results a bigger values in theoretical calculations and it is discussed with a valid reason, but when the bellow is analyzed in SolidWorks Simulation the stresses fall below the yield stress and proves the design is acceptable.

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