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# DESIGN AND OPTIMIZATION OF BELLOW SEAL VALVE USING FEA & CFD

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**Abstract**

The objective of this paper is to study and perform design, manufacturing, testing of bellow seal valve and will provide a practical comparison offering a review of inputs to the pros and cons of traditional valve technologies and manufacturing processes in contrast with the bellows sealed globe valve. The comparisons of valves will be made based on construction features, technical advantages and total cost of ownership over the life of the valve. In the present technological advancement and enhancement bellow seal valves are used for variety of applications such as ISRO & Nuclear Power Plant consists of various structures, systems and equipment which are designed with utmost safety precautions including resistance to earthquake forces. Other applications like Chemical industries, Refining&Pharmaceutical industries whose manufacturing methods utilize processing of materials are more engaged in a perpetual quest for greater and more economic output and productivity. Every critical element& parameters of a processing system plays an interrelated role in synergy with all other critical components and parameters, creating systemic conditions while mutually imposing productivity constraints.

## I. INTRODUCTION

As valve is a key component in any fluid processing system and they are used to control or regulate the flow of fluid into a designated area of the system. The valve can be operated manually or automated with a variety of actuators depending on the style and operation of the valve. A majority of valves in industry can also operate as isolation valves that shut down a specific segment of a processing system.

Valves are exposed for toomany challenging and often processed to extreme conditions. The shell material and especially all internal parts which are in a direct and constant contact with the medium have to be resistant against its destructive characteristics. The medium being in contact of the wetted part of geometry can be very aggressive, toxic, inflammable, abrasive, explosive and corrosive. The second challenge is to provide tight shutoff another issue that is often overlooked or underestimated by many designers and designed generally, has to do with the top flange and spindle sealing, which is one of the crucial points where even high quality products manufactured with highly engineered technology often fail and start to leak. In addition, pipeline and process design and operating parameters also introduce unique challenges that the valve must not only withstand, but must also be able to operate at extreme conditions.

Many Hazardous, aggressive and flammable materials are processed every day at processing plants throughout the world. In an era when environmental concerns are at an all-time high, the ability to practice strict controls over inadvertent release of environmental pollutants, accompanied by corresponding improvements in safety of environment and ecological balance, have become non-negotiable pre-conditions for a processing plant's success and reliability.

The current scenario of industries is actual processing operations and conditions, as well as the medium being passed through the system; typically pose considerable hazards in refining, chemical and pharmaceutical production and many other industries. In order to control and minimize leakage risk in these types of processing applications, it is necessary to utilize high quality valves that are capable of maintaining a tight shutoff which is enabled by a leak resistant design and construction of the bellow sealed globe valve. A high quality bellow sealed globe valve offers leak protection based on several important design principles of which a key feature is to create a leak-tight seal around the valve stem.

This paper will provide a practical comparison of several valve types and will offer a review of the pros and cons of traditional valve technologies in contrast with the bellow sealed globe valve. The comparisons will be made based on constructionfeatures, technical advantages and total cost of ownership over the life of the valve.

## II. LITERATURE REVIEW

International Society of Automation (ISA) standard for flow equation for control valve sizing (2007) provides formulas for flow coefficient calculation for different operating conditions and also serves as a guide for calculation of correction factors.

José R. Valdés et al. (2014) gave a methodology for parametric modelling of the flow coefficients and flow rate in hydraulic valves.

Expansion Joints Manufacturers Association (EJMA) standards gives calculation base for bellow functional ability and designs

V. J. Sonawane et al. designed and analysed the globe valve as control valve using CFD software. They analysed globe valves of different sizes and also for different opening conditions. The boundary conditions used were pressure inlet and pressure outlet. Calculated discharge in every case.

Brian Nesbitt (2007) gave a handbook on valves and actuators which provide the understanding of valves and actuators, properties of fluids (change of state, viscosity, density, compressibility, pH valve, hazards), valve sizing parameters and serve as a guide for valves installation and maintenance.

José R. Valdés et al. (2014) gave a methodology for parametric modelling of the flow coefficients and flow rate in hydraulic valves.

## III. LITERATURE OUTCOME

A. Spring rate calculation for various load conditions using EJMA standards
B. Understanding of basics and types of bellow seal valves.
C. Understanding about each component of bellow seal valve.
D. Understanding about the typical sizes of bellow seal valves.
E. There are different parameters that affect the valve performance including the inlet and outlet conditions and the geometry of the valve.
F. The boundary conditions for CFD analysis to be used are pressure inlet and pressure outlet.
G. Basics of pressure temperature variation.
H. Meaning of flow coefficient and its formula for different conditions.
I. Basics of correction factors used in flow coefficient calculation.

## IV. VALVE FUNCTIONABILITY

Fig.1 Bellow Valve

The design of a bellow seal valve intentionally limits the stroke length while permitting a sufficient flow rate through a large diameter of the aperture. The bellows length is adjustable to satisfy force and movement requirements. Also, the bellows diameter needs to be considered when it comes to bellow performance.

No part of media is trapped in the valve itself, as the medium flow is unobstructed by the inner structure of the valve (this is the case with the valve in an open or closed position). The packing area is completely sealed by the bellows. Very low potential for inner parts wear: No ‘soft’ materials (e.g. PTFE, sealing seals) are used. All internals are made of metal. (NOTE: Soft seat is available as an option). Very small interface between plug and seat (called a knife edge seating system) limits wear. Compared to valves with significant rotational movements, the bellow seal valve is minimally affected by abrasion between plug and seat.

Leakage prevention & environmentally safe design: The construction of a bellows system valve prevents leakage around the packing. This is especially true for the bellow seal valve built with high quality materials and construction methods, aided by the fact that the bellows is fully welded into the valve.

## V. VALVE COMPONENTS

### *A. BODY:*

The valve's body is the outer casing of most or the entire valve types that contains the internal parts or trim. The bonnet is the part of the encasingsegment through which the stem passes and that forms a guide and seal for the stem. The bonnet typically is bolted to the valve body.

### *B. STEM/SPINDLE:*

The stem serves as a connector from the bonnet to the inside of the valve and transmits this manual force. Stems are smooth for threaded for manual valves. The smooth stems are surrounded by packing material to prevent leaking medium from the valve. This packing is a wearable material and will have to be replaced during maintenance of the system. The stem must not only withstand a large amount of compression force during valve closing and openings, but also have high tensile strength during valve opening. The stem may be bellow integrated.

Fig.2 Bellow with spindle

*C. BONNET:*

The bonnet provides a leakproof casing for the valve body. The threaded section of the stem goes through a hole with matching thread profile in the bonnet. Globe valves have a bolted bonnet. A bonnet attached with bolts is used for larger or higher pressure applications in industries. The bonnet also contains the packing, a wearable material that maintains the sealing between the bonnet and the spindle during valve cycling process.

*D. PLUG/BALL:*

The closure member of the valve, plugs/ball are connected to the stem which is slid or screwed up or down to throttle the flow. Plugs are typically of the unbalance type. Unbalanced plugs are solid and are used with instrumentation valves or with low pressure drops across the valve. The advantages in these types are simpler design considerations, with one possible leak flow path at the seat and usually very lower cost. The disadvantages are the limited sizing with a large unbalanced plug geometry the forces needed to seat and hold pressure & the flow often becomes impractical.

*E. SEAT:*

The seat is the interior surface of the body which contacts the plug to form a leak-tight seal. In plug that moves linearly on a valve assembly, the plug comes into contact with the seat only when the valve is shut. In plug that rotates, the seat is always in contact with the seat, but the area of contact changes as the plug is turned. The seat always remains stationary relative to the body.

*F. SEALS:*

Mechanical seals, or packing, used to prevent the leakage of a gas or fluids from valves.

*G. HANDLE:*

A handle is used to manually control a valve from outside the valve body.

*H. BELLOWS:*

These are elastic vessels that can be compressed when pressure is applied to the outside of the vessel, or extended under vacuum. When the pressure or vacuum is released, the bellows will return to its original shape (provided the material has not been stressed past its yield strength).

## VI. IMPORTANT DESIGN CONSIDERATIONS

***A.*** *Material:*

Nearly all applications require the use of highly impervious and damage resistant materials which create more challenges for surfaces where the wetted part is in continuous contact with aggressivechemical media. Even the construction of the valve bonnet and other external parts, such as nuts and bolts, can be exposed to harsh conditions which may lead to corrosion or other structural damage.

*B. Temperature:*

Extremely low or high temperatures and rapidly changing temperatures with a huge delta values may affect.

*C. Pressure:*

Higher the pressure, greater the number of possible failure points becomes evident in a valve. Typical leak areas are packing, top flange sealing and piston/seat (some or all of which in some cases have to be redesigned to handle ultra-high pressures).

*D. Flow rate:*

Long pipes and multiple valves can reduce the flow and pressure dramatically and to promote constant flow through the system, flow co-efficiency and pressure drop ratings of a valve can become critical.

## VII. STANDARDS & SELECTION METHODOLOGY

Industrial standards vary geographically and also by particular industry & segment. The standardsare issued under the authority of ASME, DIN, and EN which currently stand as the fundamentals for valve designs, their performance parameters and specify safety requirements. Other standards and standard-setting bodies are gaining recognition globally but due consideration continues to be given to the aforementioned established standards organizations. According to industry standards, each bellow seal valve must meet or exceed the following test parameters: (for a mounted bellow seal valve, manually operated, in DIN design – other designs have the virtually same standards, as applicable to that design)

A. Requirements of EN 12266 - part 1, table 1
B. Shell test with liquid (WTA: water), valve in half open position
C. Test pressure: 1.5 x nominal pressure class
D. Testing time acc. Table no. A.2 – EN 12266
E. No leakage allowed -Tightness test with gas (WTA: air), valve in half open position
F. Test pressure: 6 bar
G. Testing time acc. Table no. A.2 – EN 12266
H. No leakage allowed -Seat tightness test with gas (WTA: air), valve in closed position
I. Test pressure: 6 bar
J. Testing time acc. Table no. A.4 – EN 12266
K. Leak rate A: absolute bubble tight

The valve material selection is done as per standards and client requirements .The modelling of valve assembly & parts is done using 3D modelling software solidworks maintaining the constraints specified in standards the bellow is outsourced from approved vendors maintaining *EJMA* calculations. The material is procured and is stocked; quality of raw material is checked performing PMI on material this material subjected to rejection and approval is loaded to vendor or production. Manufacturing is carried out according to the drawings provided to production and planning. Line inspection is done for finished products. Testing is done as per standard ASTM.

## VIII. GOVERNING EQUATIONS

The governing equations for the fluid flow are

1. Mass conservation equation or Continuity Equation [2]

$$\nabla \times (\rho V) = 0$$

Where,
ρ= density of fluid
V= velocity of fluid

2. Momentum Equation or Navier-Strokes Equation [2]

$$\nabla \times (\rho VV - \tau_f) = f_f$$

$$\tau_f = \left[-P + (-g - \frac{2}{3}\mu)\nabla \times V\right] I + 2\mu E$$

$$E = \frac{1}{2}(\nabla V + \nabla V^T)$$

Where,
$\tau_f$= Stress of fluid
$f_f$ = Volume force of fluid
P= Pressure
g= Gravitational acceleration
μ = Dynamic viscosity
I = Second order unit tensor

### A. *Calculating the Number of Convolutions Required*

The movement values indicated in sections apply to a convolution at a temperature of 20°C and based on 10,000 load changes.
The following formulas are used to calculate the necessary convolution number for a predetermined stroke. If the temperature exceeds 20°C, the movement must be reduced with the temperature factor TB.If a load change number N which differs from the basic value of 10,000 is also required, the correction must be made with the load change factor NF. If the pressure is not used 100%, the movement can be adapted with the factor FP.
Required number of convolutions for axial movement

$$W = \frac{\pm \text{Stroke}}{\pm \_ax .NF .TB .FP}$$

Required number of convolutions for lateral movement

$$W = \sqrt{\frac{\pm \text{Lateral stroke}}{\pm \_Lat .NF .TB .FP}}$$

Required number of convolutions for angular movement

$$W = \frac{\pm \text{Angular movement}}{\pm \_ .NF .TB .FP}$$

± _ax = axial stroke according to section 19 [mm]
± _ = angular stroke according to section 20 [°]
± _Lat = lateral stroke according to section 21 [mm]
W = required number of convolutions
$T_B$ = temperature factor
$N_F$ = Load alternation factor
$F_P$ = pressure load factor

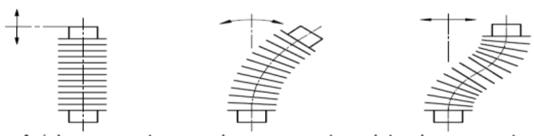



Fig.3Buckling movement for bellow

If the bellows are designed for a smaller number of load changes than the basic value of 10,000, any admissible bigger stroke on account of the convolution geometry must be checked by us. The movement values indicated in the bellows tables are only permitted for one type of movement with full use, i.e. either an axial, lateral or angular movement. Combined loads are permitted provided the total of the percentage part load does not exceed 100%.

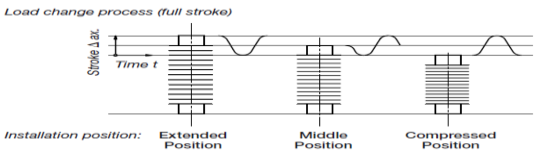



Fig.4Load summary

The load change is defined as the movement of the bellows from the neutral position over the entire stroke range and back to the neutral position. The neutral position, as the start of the movement, can be both the extended position (maximum bellows length and the compressed position (= minimum bellows length) or the middle position.

### *B. Spring Rate per Convolution Calculating the Bellows Adjustment Forces*

The spring characteristic is specified for all 3 types of movement as the specific value per convolution and decreases with increasing number of corrugations, i.e. linearly in the case of axial and angular movements and to the power of 3 in the case of lateral movements. At higher temperatures, the spring characteristic must be reduced according to the decreasing modulus of elasticity.
The factor $T_F$

a) Spring characteristic of a bellows with an axial movement

$$C_{ax} = \frac{cax}{W}[TF]\frac{N}{mm}$$

b) Spring characteristic of a bellows with an angular movement

$$C_a = \frac{ca}{W}(TF)\frac{Nm}{<°}$$

c) Spring characteristic of a bellows with lateral plane parallel movement

$$C_{lat} = \frac{clat}{W3}(TF)\frac{N}{mm}$$

$C_{ax} C_a C_{lat}$ = spring rate of the whole bellow
$c_{ax}$ $c_a$ $c_{lat}$ = spring rate per convolution
$T_F$ = Temperature factor to calculate spring rate at higher temperatures
W = chosen number of convolutions (of a bellow)
The values for the spring characteristics apply to the standard version with a tolerance of ± 30%. A smaller tolerance requires special measures concerning raw material and production and therefore is only possible subject to agreement.

## IX. TESTING METHODS & CRITERIA

### *A. Hydrostatic Shell Pressure Test.*

Each valve shall be testedfor shell test at a gage pressure not less than 1.5 times the 38°C (100°F) pressure rating, rounded off to the next higher 1 bar (25 psi) increment. The test to be conducted with medium water, which may contain a corrosion inhibitor, with kerosene, or with other suitable fluid, provided such fluid has viscosity not greater than that of water. The test fluid temperature shall not exceed 50°C (125°F). Conduct teston valve in the partially open position, test time required for inspection after the valve is as per standard and is under shell test pressure.

### *B. Acceptability.*

Visually detectable leakage through the pressure boundary is not acceptable. The pressure boundary includes, body, bonnet, all sealing areas; however, leakage through the stem seals or stem packing shall not be cause for rejection.

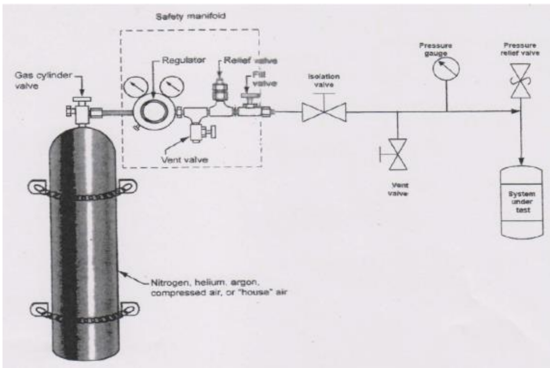



Fig.5Testing setup

Stem seals or stem packing exempted from the shell test pressure leakage requirement shall be capable of retaining pressure up to the 38°C (100°F) pressure rating without visible leakage.

### *C. Pneumatic Shell Pressure Test:*

Pneumatic tests are potentially more dangerous than hydrostatic because of the higher level of potential energy. Pneumatic tests may be performed only when at least one of the following conditions exists:

A. When pressure systems are so designed that they cannot be filled with water.
B. When pressure systems are to be used in services where traces of the testing medium cannot be tolerated.

## X. ANALYSIS USING FVM

Finite volume method is employed to discretize the fluid motion equation. All simulations are done in in solid works to compare the results.Choosing a SolverSolid works allows numerical methodsPressure based solver

### *A. Pressure Based Solver*

The pressure-based solver is applicable for a wide range of flow regimes from low speed incompressible flow to high-speed compressible flow. It requires less memory (storage). It also allows flexibility in the solution procedure. The pressure-based coupled solver (PBCS) is applicable for most single phase flows involved, and yields superior performance to the pressure-based (segregated) solver involved. This is not available for multiphase (Eulerian), periodic mass-flow and NITA cases. This solver requires and uses 1.5–2 times more memory than the segregated solver.

| **Name** | **Unit** | **Value** | **Delta** | **Criteria** |
|---|---|---|---|---|
| P1 | kgf/cm$^2$ | 300.00 | 8.9270e-012 | 0.0009 |
| P2 | kgf/cm$^2$ | 299.69 | 0.0031 | 0.0037 |
| Q | kg/s | 0.1000 | 0 | 0.0001 |
| PD | kgf/cm$^2$ | 0.31 | 0.0031 | 0.0043 |
| Cv | | 5.6542 | 0.0285 | 0.0290 |

### *B. Selecting Appropriate Model for Simulation*

Viscous model is based on the type of flow i.e. the flow is either laminar or turbulent. The type of flow is governed by a dimensionless number called Reynolds number.
Reynolds number is defined as

$$Re_D = \frac{\rho V D}{\mu}$$

Where,
*ρ= Density of fluid*
*V= Velocity of fluid*
*D= Hydraulic diameter*
*μ= Dynamic viscosity of fluid*
If $Re_D < 2300$ then the flow in pipe is considered as laminar, and if it is more than 4000 than the flow is considered as turbulent.

### *C. Calculating Reynolds Number for the Analysis*

For the giving simulation the fluid is water, and the hydraulic diameter is 18.32 mm. considering the least velocity used for simulation i.e. 8 m/s, the valve of Reynolds number is

$$Re_D = \frac{998.2 \times 8 \times 18.32 \times 10^{-3}}{0.001003}$$

$$Re_D = 145{,}858.62$$

As the valve of Reynolds number is more than 4000, the flow is turbulent, thus realizable k-epsilon model will be the best suited model for the analysis.

| NAME | MINIMUM | MAXIMUM |
|---|---|---|
| Pressure [kgf/cm$^2$] | 299.50 | 300.29 |
| Temperature [°C] | 24.99 | 25.01 |
| Density [kg/m$^3$] | 996.26 | 996.26 |
| Velocity [m/s] | 0 | 8.397 |
| Velocity (X) [m/s] | -8.390 | 2.430 |
| Velocity (Y) [m/s] | -4.024 | 3.426 |
| Velocity (Z) [m/s] | -3.820 | 3.833 |
| Temperature (Fluid) [°C] | 24.99 | 25.01 |
| Vorticity [1/s] | 0.190 | 27240.463 |
| Dynamic Pressure [kgf/cm$^2$] | 0 | 0.36 |
| Friction Coefficient [ ] | 0 | 17.7139 |
| Shear Stress [kgf/cm$^2$] | 0 | 4.67e-003 |
| Reference Pressure [kgf/cm$^2$] | 1.03 | 1.03 |
| Specific Heat (Cp) [J/(kg*K)] | 4127.1 | 4127.2 |
| Dynamic Viscosity [Pa*s] | 0.0009 | 0.0009 |
| Prandtl Number [ ] | 6.1291696 | 6.1320056 |
| Fluid Thermal Conductivity [W/(m*K)] | 0.5992 | 0.5993 |
| Heat Transfer Coefficient [W/m$^2$/K] | 0 | 0 |
| Surface Heat Flux [W/m^2] | 0 | 0 |
| Turbulent Viscosity [Pa*s] | 1.4554e-008 | 0.3977 |
| Turbulent Time [s] | 1.701e-004 | 3.505 |
| Turbulent Length [m] | 6.753e-007 | 8.026e-004 |
| Turbulent Intensity [%] | 0.03 | 1000.00 |
| Turbulent Energy [J/kg] | 9.400e-007 | 9.227 |
| Turbulent Dissipation [W/kg] | 5.54e-007 | 19461.22 |

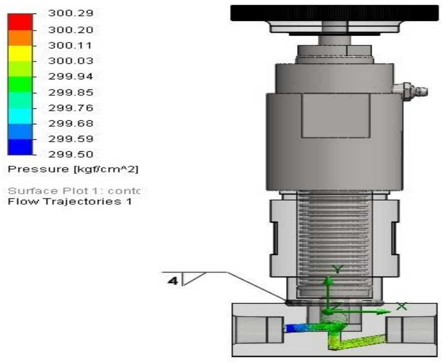


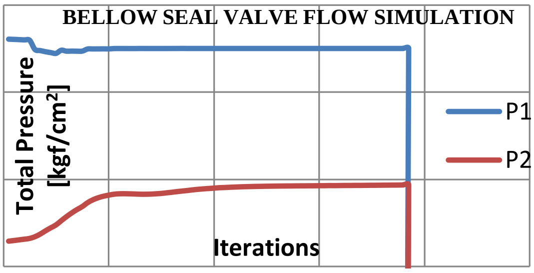

Figure-5Analysis results

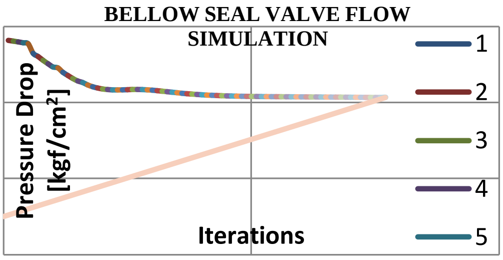
Results obtained are as follows

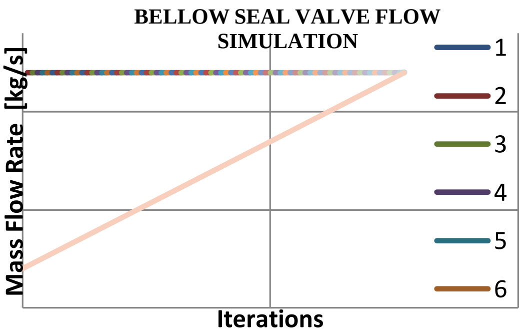
## I. RESULTS

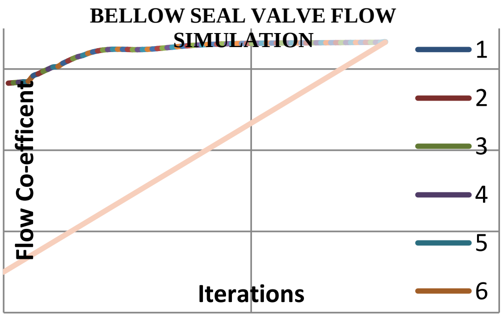
Other parameters of computational fluid domain considered during analysis are,

## II. PARAMETERS




## XI. FUTURE SCOPE

Currently, with the help of FVM, the flow coefficient of needle valve is calculated. Next step in the project is to find out the stress and deformation developed on spindle plug with the help of FEM.

In the finite element method, the actual continuum or body of matter like solid, liquid or gas is represented as on assemblage of sub divisions called finite elements. These elements are considered to be interconnected at specified joints, which are called nodes or nodal points. The nodes usually lie on the element boundaries where adjacent elements are considered to be connected. Since the actual variation of the field variable (like displacement, stress, temperature, pressure and velocity) inside the continuum is not known, we assume that the variation of field variable inside a finite element can be approximated by a simple function. These approximating functions (also called interpolation models) are defined in terms of values at the nodes when field equations (like equilibrium equations) for the whole continuum are written. Structural analysis will also be carried out in ANSYS.

### *A. Understanding the Parameters*

After analysing the valve, parameters affecting the efficiency of the valve will be listed out. At different openings pressure and temperature curve will be plotted to have a better understanding of the parameters. After finalising all the parameters a regression equation will be formed covering all the parameters that affect the valve efficiency.

### *B. Practical Testing*

The results found by finite element method and design of experiments will be tested practically to understand the gap between theoretical and practical problems. This will also help to find you constants to make regression equation more accurate.

## XII. REFERENCES

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