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Pressure Vessel Optimization a Fuzzy Approach

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Abstract
Optimization has become a significant area of development, both in research and for practicing design engineers. In this work here for optimization of air receiver tank, of reciprocating air compressor, the sequential linear programming method is being used. The capacity of tank is considered as optimization constraint. Conventional dimension of the tank are utilized as reference for defining range. Inequality constraints such as different design stresses for different parts of tank are determined and suitable values are selected. Algorithm is prepared and conventional SLP is done in MATLAB Software with C++ interface toget optimized dimension of tank. The conventional SLP is modified by introducing fuzzy heuristics and the relevant algorithm is prepared. Fuzzy based sequential linear programming is prepared and executed in MATLAB Software using fuzzy toolbox and optimization tool box and corresponding dimension are obtained. After comparison FSLP with SLP it is observed that FSLP is easier in execution.
Keywords: Fuzzy, Matlab, SLP, FSLP, Stress, Strain, Optimization**.**

I. I.INTRODUCTION

A pressure vessel is a container designed to hold gases or liquids at a pressure different from ambient pressure. In the industrial sector, pressure vessels are design to operate safely at a specific pressure and temperature, technically refereed to as Design pressure and Design temperature which is governed by design code ASME .Compressed air storage tank at automobile service station, cylinder for LPG, air vessels of pneumatic brakes in automobiles and oxyacetylene tank at welding workshop are a few applications of pressure vessels. In different chemical plants, the containers or vessels of pressurized liquid or gases are also pressure. Among these commercial products, a common feature is that they must undergo a certain high working pressure with an appropriate safety factor and low maintenance costs. [1][13].

Determination of safest and most economical product within manufacturing and code constraint is the goal for most of the pressure vessel design problems. To satisfy this goal under circumstances, one has to go for optimization techniques. In conventional design, factor of safety is always introduced to determine safe design parameters. But in case of complicated design problems such as pressure vessel there are so many constraints such as stress values on shell, crown and knuckle section of head, residual weld stress, thermal stress etc. Thus; incorporating factor of safety for each allowable stress such as stresses induced in the crown, knuckle, and shell section to determine safe dimensions becomes difficult task. To obtain the optimized dimensions i.e. safe and economical within given constraint, optimization is necessary. Optimization problems are mostly non-deterministic & fuzzy in nature. This nondeterministic or fuzzy condition is not only in design variables but within various parameters with allowable limits as well. The fuzzy membership function of Fuzzy controller can be optimized via gradient descent and kalman filtering. The optimization methods are explained based on simulated fuzzy automotive cruise controller. The unconstrained optimization resulted in better performance than constrained optimization [2] [3].

II. STRESS ANALYSIS OF AIR RECEIVER TANK

The pressure vessels usually consist of a pressure resisting shell together with flange rings and fastening devices for assembly of the mating parts. Strength is an inherent property of a mechanical element and is the characteristic of the material and is there even when no external load is applied on the mechanical element. To avoid the pressure vessel failure the design engineer must have positive assurance that stresses generated will never exceed the strength. Stress analysis of a pressure vessel is a very sophisticated area.{B]Stress analyses can be performed by analytical or experimental method However when member has geometric shapes, discontinuities, it becomes difficult to express the continuous internal strain distribution mathematically and obtain a particular solution. When the problem is too complex and beyond analytical solution, resource must be made to experimental means. Some of the commonly used method includes Strain gauge, photo elastic, Moiré method [4].

Specifications of the air receiver tank which is used for experimental study, are obtained from 'DATACONE', is as under, Conventional Design Data: Code of construction: - SA 516.70 Tank Capacity: -586 lit Working pressure (Pw): - 10 kg/cm² Design pressure (Pd) - 12.20 kg/cm² Test pressure (p) 18.5 kg/cm² Welded joint efficiency (η) = 0.85 a) Theoretical stress analysis Stress on the various parts can be calculated theoretically as follows

1) Stress induced in shell

The stresses induced in shell of an air receiver tank of reciprocating compressor can be determined as follows Maximum induced longitudinal stress

=Pd/ (4ts) = 45.11 N/mm^2

(1)Maximum induced circumferential stress

=Pd/ (2ts) = 90.23 N/mm^2

(2) Stress induced in head Crown region

The stresses induced in the meridional and circumferential directions are same.

Hoop stress = Meridional stress óh = óm = p rc / 2 th =58.49N/mm2

(3)Knuckle region

Meridional stress (óm) = p r2 / 2 th

=58.49 N/mm2 (4)

Circumferential stress

(óh)=pr2(2–r2/rk)/2th = -134.34N/mm2 (5) [9]

b) Experimental stress analysis

Fig (1). Experimental setup for stress analysis

The strain measured on shell is shown in Table 1

Internal pressure Kg / cm^2	εx μ strain	εy μ strain
6	28	124
8	38	174
10	47	219
12	62	266
14	77	312

The stress measured on shell is shown in Table 2

Internal pressure Kg / cm^2	(σ_1) N/mm^2	(σh) N/mm^2
6	13.6	27.83
8	18.8	37.46
10	23.6	48.25
12	28.76	57.84
14	34.65	68.67

The strain values for knuckle and crown section are measured. Using stress-strain relation corresponding values for stress is obtained. Then these values of different induced stresses are used to plot the graphs. After extrapolation the stress values for different parts are obtained.

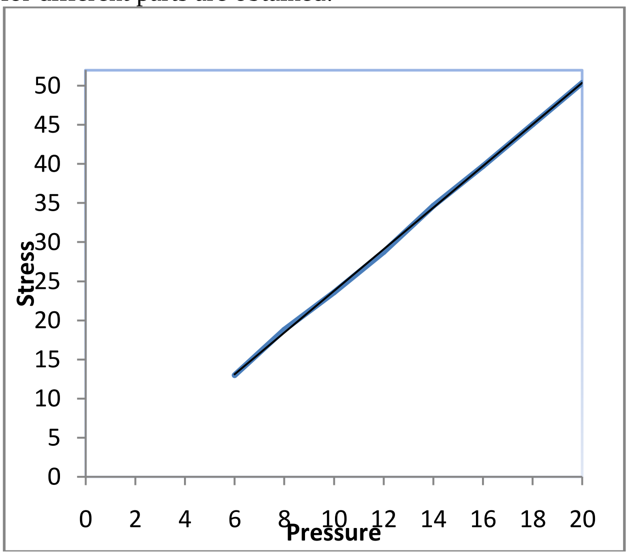

Fig (2) longitudinal stress induced in shell

c) Finite element analysis using ANSYS ANSYS is a software package designed for engineers who deals with analysis of complex structures and component. In this work we use Structure to perform sensitivity study of a model to show which variables have the greatest effect on structural performance and synthesize an optimized design based on real life constraints and performance objectives.

The stress values at test pressure on various parts of Air Receiver Tank are noted as output of the analysis [7].

III. COMPARISON OF STRESS VALUES

Table 3 shows stress values are obtained using Theoretical, Experimental, and Finite Element Analysis Using ANSYS.

Table 3 Comparison of stress value

Stress	Thero.	Expt.	F.E.A.
σl	45.11	45.92	47.68
σh	90.23	91.5	91.14
σm	58.49	61.2	64.14
σc	58.49	62.31	64.14
σm	58.49	57.5	60.14
σc	-134	-141	-102

IV. PROBLEM FORMULATION FOR SLP

Objective function is given as, F (x) = Volume of material of air receiver tank
= Volume of material of cylindrical shell
+2(Volume of material of Torispherical head)
Volume of material of Torispherical head
= (surface area of knuckle region + surface area of crown region)*(thickness of head)[2] [3]
F(x) = (π (R+ts)2L- πR^2L) + 2 (2πrc(β(Rrc)/
57.3 + rcsin β)th + 2 π rk
2(1-sinβ) th) (6)[9]
The objective function can be written as,
F (x) = 6.28 x1 x2 x3 + 3.14 x3
2 x2 + 6.28 x4
2 x6 +
.3443 x5 x6 x1- .3443 x5
2 x6- .256 x5 x6 x1
2/(x5-
x4) + .0366 x6 x1/(x5- x4) + .256 x5 x6 x1 x4/(x5-
x4)- .0366 x6 x4 x1
2/(x5- x4)+ .2194 x6 x1 x5
2/(
x5- x4)- .2194 x6 x4 x5
2/ (x5- x4)+12.56 x5
2 x6 cos
[(x1/(x5- x4))- x1
2/6 x5(x5- x4)- x4/(x5- x4)+ x1
x4/(6 x5(x5- x4))][(x1/(x5- x4))- x1
2/6 x5(x5- x4)-
x4/(x5- x4)+ x1 x4/(6x5(x5- x4))]-12.56 x4
2 x6 cos
[(x1/(x5- x4)) -x1
2/6 x5(x5- x4)- x4/ (x5- x4)+ x4
x1/(6 x5(x5- x4))][(x1/(x5- x4))- x1
2/6 x5(x5- x4)-
x4/(x5- x4)+ x1 x4/(6x5(x5- x4))] (7)
Constraints in the form of Design Variables
g1(x) = 0.9074 x1/x3 – 45.11 ≤ 0
g2(x) = 1.81485 x1/x3 – 90.23 ≤ 0
g3(x) = 1.81485 x7/x6 -.9074 x7/x6x4 + 134.34 ≤ 0
g4(x) = 0.9074 x7/x6 –58.50 ≤ 0
g5(x) = 0.9074 x5/x6 – 58.50 ≤ 0 (8)

V. FUZZY KNOWLEDGE BASED CONTROLLER

Fuzzy controllers, contrary to classical controllers are capable of utilizing knowledge elicited from human operators. This is crucial in control problems for which it is difficult or even impossible to construct precise mathematical models. These difficulties may result from inherent nonlinearities, the time varying nature of the processes to be controlled, large unpredictable environmental disturbances and a host of other factors.

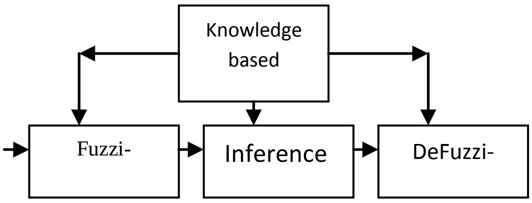

Fig (3) fuzzy logic controller

VI. FUZZY DESIGN

A fuzzy logic controller controls the SLP performance with the help of boundary control factor. This tightens constraints and pulls the solution back towards feasible space. It also uses the move limit reduction factor to rapidly converge the solution. Fuzzy heuristics modify the move limits according to changes in search direction. This prevents premature termination of iteration. The five constraints which are inputs and Move limit factor (β) Boundary control factor (α) are output.

Step1: Define the universe of disclosure.
The range of values that input and output may take is called as universe of disclosure. It is necessary to define the universe of disclosure for all the input and output crisp values of fuzzy controller.

Step 2: Fuzzify the inputs
The inputs to the fuzzy controller are the constraints 1 to 5. Gaussian membership function is used to fuzzify these inputs. (Feasible, Binding, Infeasible, Very infeasible)

Step 3: Fuzzify the outputs
The outputs of fuzzy controller are move limit factor and boundary control factor

Step 4: Creation of fuzzy rule base
Thus, fuzzy heuristic for Sequential linear programming can be expressed in the form of fuzzy rules as
1 If gj(x) is feasible, then β is increased.
2 If gj (x) is binding, then β is reduced much.
3 If gj (x) is infeasible, then β is reduced.
4 If gj (x) is infeasible, then α is unchanged.
5 If gj (x) is infeasible then αj is reduced

6 If gj(x) is very infeasible, then α is reduced much. . where gj (x) are input constraints αj is boundary control factor at
j = 1 to 5 β is move limit factor.
Step5: Clipping of fuzzy output and de fuzzification
For every input, constraint is determined and applied to fuzzy rules and checked whether it satisfies any of the rule or combination of these rules. If it is satisfied, the rules are said to be fired [10] [11].

VII. ALGORITHM FOR SLP WITH FUZZY HEURISTICS

1 Selection of design variables
x0 = [x1
0,x2
0,x3
0,x4
0,x5
0,x6
0,x7
0]
Δx0=[Δx1
0,Δx2
0, Δx3
0, Δx4
0, Δx5
0, Δx6
0, Δx7
0]
β = [β1, β2, β3, β4, β5, β6, β7]
qmax = maximum iteration
ub = [u1
b,u2
b,u3
b,u4
b,u5
b,u6
b,u7
b]
u1 = [u1
1,u2
1,u3
1,u4
1,u5
1,u6
1,u7
1]
dftol = dftol2 = 0.001
where x0 – starting point
Δx0 = gradient step direction
β = move limit factor
dftol – Absolute objective convergence
dftol2 – relative objective convergence
2. Let x* = x0
3 Evaluation of cost function at current design Variables f* = f(x0) f*old = HUGE_VAL
4.Evaluation of inequality constraints at current design variables gj* = gj (x0) j = 1 to 5
5.Evaluation of equality constraints at current design variables h* = h(x0)
6 Fuzzy heuristics
1 If gj (x) is feasible then β is increase
2 If gj (x) is binding then β is reduced much
3 If gj (x) is infeasible then β is reduced
4 If gj (x) is feasible then αj is unchanged
5 If gj (x) is infeasible then αj is reduced
6 If gj (x) is very infeasible then αj is reduced much
7 Let q = 0
8. q = q + 1
9 Evaluation of upper and lower limits ui = min (Δxi, max (ubi- xiq)) li = min (Δxi, max (xi q-lib))
10 Evaluation of cost and constraint function gradients c = [df/dx1, df/dx2, df/dx3, df/dx4, df/dx5, df/dx6, df/dx7] n = [dh/dx1, dh/dx2, dh/dx3, dh/dx4, dh/dx5, dh/dx6, dh/dx7] aj = [dgj/dx1, dgj/dx2, dgj/dx3, dgj/dx4, dgj/dx5, dgj/dx6, dgj/dx7] j = 1 to 5
11.Use of linear programming to find δx minimize
f* + c δ x
Subject to,
αjgj* +aj δ x ≤ 0 j = 1 to 5
h* + aj δx = 0
li≤ xi ≤ ui i = 1 to 7
12 x*= x* + δx
f*old = f*
f* = f(x*)
14. gj = gj(x*) j = 1 to 5
h* = h(x*)
15Fuzzy rules will be fired for the aboveoptimized values of x*
(Step 12 to 14)
If gj(x) is feasible then β is increase
If gj(x) is binding then β is reduced much
If gj(x) is infeasible then β is reduced
If gj(x) is feasible then αj is unchanged
If gj(x) is infeasible then αj is reduced
If gj(x) is very infeasible then αj is reduced
much
16 Δx = β (Δx)
17 df = {f* old- f*}
18 df2 = df / f
19 If (df < df tol)
Design is feasible
Else if (df2 < (dftol) 2)
Design is feasible
Else if q > qmax
Increase number of iteration
Else GO To Step 8
END
END [8] [12].

VIII. CONCLUSION

The scope of work is to obtain optimized dimensions of an air receiver tank of reciprocating compressor using fuzzy logic.

Equality constraint for the optimization is the capacity of the tank. Inequality constraints are the respective design stresses at shell part, knuckle part and crown part of the tank for maximum internal pressure Conventional dimensions are used for initial fixation of ranges for Sequential linear Programming and Fuzzy based Sequential linear Programming for optimization. FSLP is easier than conventional SLP. SLP has a limitation such as not suitable for arbitrary starting point.

It can be stated that Conventional SLP can be improved by introducing fuzzy heuristics other optimization technique can also be employed. Fuzzy logic can also be used for Sequential Quadratic programming which expands the possibilities of Sequential programming to be used for various design optimization problems.

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