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Optimization of Plate Thickness of Air Receiver Tank of Centrifugal Compressor Using Neuro Fuzzy Logic

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Abstract: Optimization has become a significant area of development, both in research and practice among design engineers. In this paper for optimization of air receiver tank, of reciprocating air compressor, the SLP method is being used. The capacity of tank is considered as optimization constraint. Conventional dimension are utilized as reference. Inequality constraints such as different design stresses for different parts are determined theoretically, experimentally and with the help of ANSYS software. Algorithm is prepared and conventional SLP is done in MATLAB software to get optimized dimension of the air receiver tank. The conventional SLP is modified by fuzzy heuristics and the relevant algorithm is prepared. Fuzzy based SLP is prepared and executed in MATLAB software, corresponding dimension are obtained. Comparing FSLP with SLP it is observed that FSLP is easier in execution. In FSLP starting point is easily accepted while it is cumbersome in case of conventional SLP. It can be observed that the thickness obtained from FSLP is 5% more than suggested by SLP method for crown section. Neuro Fuzzy logic can also be used for SQP which expands the possibilities of Sequential programming for various design optimization problems.

Keywords: Fuzzy, SLP, FSLP, Stress, and Optimization

I. INTRODUCTION

Pressure vessel is a leak proof container and is very common in engineering application as well as in day-to-day life. At every bicycle mart and tyre works one will see an air receiver tank of reciprocating compressor, which is nothing but pressure vessel. 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 vessels. Generally employing a spiral welding using annular force makes cylindrical pressure vessel. As change in ratio of thickness on layer is accompanied by change in the reinforcement strength. Even small deviation from optimum design parameters can reduce the load carrying capacity of composite structure [9].

II. STRESS ANALYSIS OF AIR RECEIVER TANK

Pressure vessels commonly have the form of spheres, cylinders, ellipsoids or some combinations of these. Based on the ASME code, stresses are categorized into three types with different stress limits. The stress limits change for different service levels. Since these stress limits change for the types of stresses and the service levels, multiple loading conditions should be utilized during an optimization. According to the ASME code, the failure condition can be evaluated by comparing the stress intensity, which was obtained from the stress linearization at the concerned section, with the prescribed one. The three categories of stresses are primary, secondary, and peak. Primary stresses are load controlled; secondary stresses are displacement controlled; and peak stresses are local in nature. Primary and secondary stresses can be a membrane or a bending. (A) In practice, vessels are usually composed of a complete shell together with flange ring and fastening devices for connecting and securing mating parts. The main purpose is to contain a media under pressure and temperature; however, in doing so they are subjected to the action of steady and dynamic support loading, piping reaction, thermal shocks results in various stresses [18].

A. Comparison of Stress Values

Table 1 Comparison of stress value

Parameter	Theoretical	Expt.	F.E.A.
σ_l	45.11	45.92	47.68
σ_h	90.23	91.5	91.14
σ_{mcs}	58.49	61.2	64.14
σ_{cs}	58.49	62.31	64.14
σ_m	58.49	57.5	60.14
σ_c	-134.34	-141.28	-102

Table 1 shows stress values are obtained using Theoretical, Experimental, and Finite Element Analysis Using ANSYS

Circumferential stress on knuckle section of head (σ_c), Meridional stress on knuckle section of head (σ_m)

Circumferential stress on crown section of head (σ_{cs}), Meridional stress on crown section of head (σ_{mcs})
Circumferential stress on shell (σ_h), Longitudinal stress on shell (σ_l)

III. PROBLEM FORMULATIONS FOR SEQUENTIAL LINEAR PROGRAMMING

Aim of this work is to determine the optimum dimensions of air receiver tank. To workout the same one need to write the expressions for objective function and constraints. For the convenience objective function is considered as the volume of material of air receiver tank of reciprocating compressor.

Objective function is given as,

$F(x) = \text{Volume of material of air receiver tank} = \text{Volume of material of cylindrical shell} + 2(\text{Volume of material of Torispherical head})$

Volume of material of Torispherical head = (surface area of knuckle region + surface area of crown region)*(thickness of head)

$$F(x) = (\pi (R+t_s)^2 L - \pi R^2 L) + 2 (2\pi r_c (\beta(R-r_c)/57.3 + r_c \sin \beta) t_h + 2 \pi r_k^2 (1-\sin \beta) t_h) \quad [10],[18]$$

where,

$R = \text{radius of shell} = x_1$

$L = \text{length of shell} = x_2$

$t_s = \text{thickness of shell} = x_3$

$r_k = \text{knuckle radius of head} = x_4$

$r_c = \text{crown radius of head} = x_5$

$t_h = \text{thickness of head} = x_6$

$r_2 = \text{radius of curvature} = x_7$

$\beta = \text{angle included by knuckle radius} = 3.14/2 - \text{angle included by crown radius}$

where as, $\sin(\Phi) = (R-r_k)/(r_c-r_k) = (x_1-x_4)/(x_5-x_4)$

$$= \pi/2 - (x_1/(x_5-x_4) - x_1^2/(6 x_5(x_5-x_4)) - x_4/(x_5-x_4) + x_1 x_4/(6 x_5(x_5-x_4)))$$

The objective function can be written as,

$$F(x) = 6.28 x_1 x_2 x_3 + 3.14 x_3^2 x_2 + 6.28 x_4^2 x_6 + .3443 x_5 x_6 x_1 - .3443 x_5^2 x_6 - .256 x_5 x_6 x_1^2/(x_5-x_4) + .0366 x_6 x_1/(x_5-x_4) + .256 x_5 x_6 x_1 x_4/(x_5-x_4) - .0366 x_6 x_4 x_1^2/(x_5-x_4) + .2194 x_6 x_1 x_5^2/(x_5-x_4) - .2194 x_6 x_4 x_5^2/(x_5-x_4) + 12.56 x_5^2 x_6 \cos [(x_1/(x_5-x_4)) - x_1^2/6 x_5(x_5-x_4) - x_4/(x_5-x_4) + x_1 x_4/(6 x_5(x_5-x_4))]/[(x_1/(x_5-x_4)) - x_1^2/6 x_5(x_5-x_4) - x_4/(x_5-x_4) + x_1 x_4/(6 x_5(x_5-x_4))]] - 12.56 x_4^2 x_6 \cos [(x_1/(x_5-x_4)) - x_1^2/6 x_5(x_5-x_4) - x_4/(x_5-x_4) + x_1 x_4/(6 x_5(x_5-x_4))]]/[(x_1/(x_5-x_4)) - x_1^2/6 x_5(x_5-x_4) - x_4/(x_5-x_4) + x_1 x_4/(6 x_5(x_5-x_4))]]$$

Capacity of tank as equality constraint $h(x)$ and expressing it in the terms of design variables as follows,

Capacity of tank is $5.86 \times 10^8 \text{ mm}^3$ i.e. (586 lit)

Volume of tank = Volume of shell + 2(Volume of Torispherical head)

$$\text{Therefore, } h(x) = 3.14 x_1^2 x_2 + 2.1008 x_1^3 - 5.86 \times 10^8 = 0$$

The five inequality constraints, $g(x)$ are longitudinal and circumferential stress in shell, circumferential and meridional stress for knuckle section and meridional and circumferential stress for crown section of head. Representing these constraints in the form of design variables [3], [11].

IV. 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.

Knowledge here means a model, which provides a conceptual structure to capture those aspects of the project, which accurately represent its behavior. A knowledge based system for closed loop control is a control system that enhances the performance reliability and robustness of control by incorporating knowledge as in the case of manual modes of operation. This cannot be accommodating in the analytical model. [7]

In particular, fuzzy knowledge based controller replaces completely the conventional controller in the closed loop. Specific knowledge representation technique derived from fuzzy logic can be utilized to build knowledge-based controller. The methodology of the same is shown below as block diagram. Figure 1

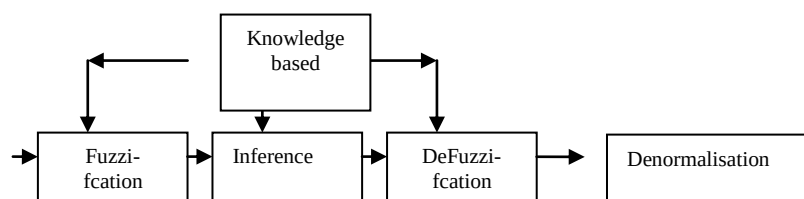


Figure 1 Fuzzy Block Diagram

A. Fuzzy Design Procedure

Step 1 defining 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. The universe of disclosure for individual inputs and outputs are given in table 5.1

Table 2 Universe of disclosure for individual inputs and outputs

Constraint	Input/ output	Minimum value	Maximum value
σ_l	1	-5	10
σ_h	1	-10	20
σ_{mcs}	1	-45	30
σ_m	1	-7	9
σ_c	1	-50	20
β	0	0.5	1.2
α	0	0.5	1.2

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. The input variable can be discredited in the following fuzzy sets table 3 (Feasible, Binding, and Infeasible, Very infeasible)

Table 3 Fuzzify inputs

Fuzzy Variable Constraint	Feasible	Binding	Infeasible	Very Infeasible
1	(-5) to (-2)	(-3) to (3)	(3) to (7)	(6.5) to (10)
2	(-10) to (-2)	(-4) to (5)	(3.5) to (10.5)	(10) to (20)
3	(-45) to (-10)	(-11) to (6)	(5) to (20)	(20) to (30)
4	(-7) to (-3)	(-4) to (3)	(4) to (6)	(5) to (9)
5	(-50) to (-10)	(-20) to (1)	(1) to (14)	(10) to (20)

Step 3 fuzzify the outputs

The outputs of fuzzy controller are move limit factor and boundary control factor. Fuzzified outputs assigning membership function are shown in table 4

Table 4 Fuzzified outputs

For β	For α	Fuzzy variable
[1.00]	[0.95,1.05]	Unchanged
[0.9]	[0.87,0.912]	Reduced
[0.5]	[0.45,0.55]	Reduced much
[1.05]	-----	Increased

Step 4 creation of fuzzy rule base

It is necessary to construct a set of rules that describe the operation of fuzzy logic controller. The heuristic proposed are

I) if the design point is feasible, then increase the move limits slightly

II) If the design point is very infeasible, then slightly reduces the move limit factor and tightens constraints

III) If the design factor is near the binding constraints, then rapidly reduce

The first heuristic is an attempt to speed up the movement when design point is inside feasible space and constraint boundaries are far away. The second heuristics are encouraging movement towards feasible space by tightening the constraints aggressively. It shifts the next solution closer to feasible space. Once the binding constraints are identified, the third heuristic aims at rapid convergence by shrinking the move limits quickly. Thus, fuzzy heuristic for Sequential linear programming can be expressed in the form of fuzzy rules as

- 1 If $g_j(x)$ is feasible, then β is increased.
- 2 If $g_j(x)$ is binding, then β is reduced much.
- 3 If $g_j(x)$ is infeasible, then β is reduced.

- 4 If $g_j(x)$ is infeasible, then α is unchanged.
 - 5 If $g_j(x)$ is infeasible then α_j is reduced
 - 6 If $g_{j(x)}$ is very infeasible, then α is reduced much. .
- Where $g_j(x)$ are input constraints
 α_j is boundary control factor at $j = 1$ to 5
 β is move limit factor.

Step 5 Clipping of fuzzy output and defuzzification

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. Accordingly, the problem defined here, four rules are fired. Each of four rules is satisfied for the applicability of five constraints to get individual output of move limit factor and boundary control factor. The overall output of each of these rules is determined by clipping in the form of membership function

The outputs are then defuzzified by the method of area defuzzification using MATLAB software and the results are obtained [20].

V. NEURAL NETWORKS

Neural Networks are a different paradigm for computing: Von Neumann machines are based on the processing/memory abstraction of human information processing.

- Neural networks are based on the parallel architecture of animal brains.

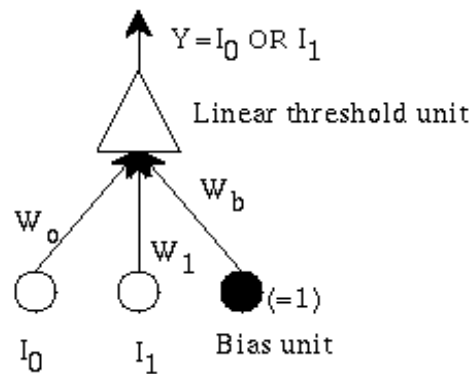


Fig 2 Simple Perceptron

Neural networks are a form of multiprocessor computer system, with

- simple processing elements
- a high degree of interconnection
- simple scalar messages
- adaptive interaction between elements

A biological neuron may have as many as 10,000 different inputs, and may send its output (the presence or absence of a short-duration spike) to many other neurons. Neurons are wired up in a 3-dimensional pattern. Real brains, however, are orders of magnitude more complex than any artificial neural network so far considered [21][22].

VI. RESULTS AND CONCLUSION

Design Variable	Conventional Dimensions in mm	Optimum dimensions obtained using fuzzy based SLP in mm	Optimum dimensions obtained using Neuro fuzzy based SQP in mm
Radius of shell	353	353	351
Length of shell	1200	1211	1208
Thickness of shell	7.1	7.55	7.5
Crown radius of head	593	589	585
Knuckle radius of head	138	135.2665	140
Thickness of head	9.2	9.1685	9.35

FSLP is easier than conventional SLP. Even though the later is easy to prepare, it has a limitation such as not suitable for arbitrary starting point. This problem is overcome by fuzzy based SLP, so as to choose arbitrary starting point for iteration. This can be obtained by introducing move limit factor and boundary control factor.

Thus it can be stated that Conventional Sequential linear programming can be improved by introducing fuzzy heuristics

In this work optimization method used is sequential linear programming, applied with fuzzy logic and result compared with Sequential Quadratic programming with Neuro fuzzy. Other optimization technique can also be employed with Fuzzy logic, which expands the possibilities for various design optimization problems.

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