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A Fuzzy PD Controller for Structural Optimization of Axis Symmetric Shells

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Outline

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6. Optimization Results (2 case studies)
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Research Objectives

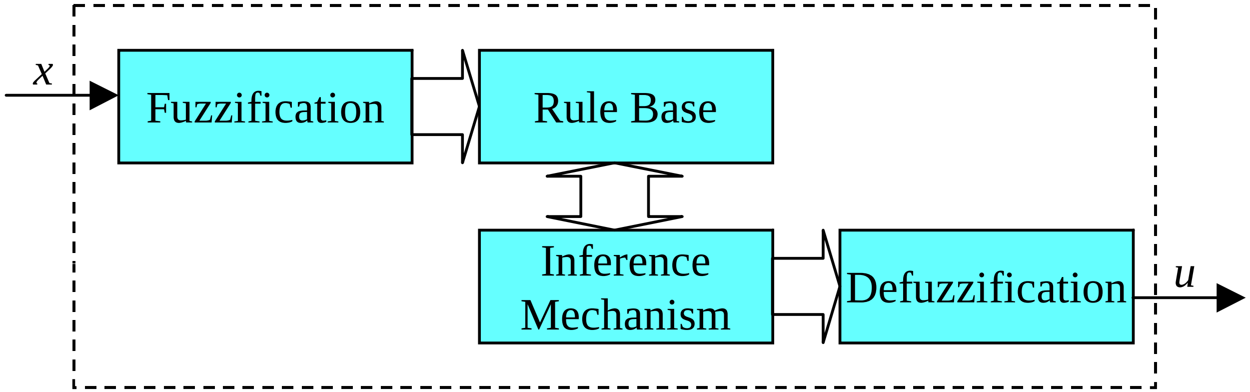
- ❖ Traditional numerical optimization algorithms treat the optimization problem as pure mathematical problems. Engineering knowledge about the problem is not utilized in the optimization process.

- ❖ In axis symmetric shell structures, the discontinuity at the intersection of two shells causes stress concentration, which often causes failure of the shell structure.

- ❖Develop a fuzzy PD control for determining the optimal thickness profile of axis symmetric shell structures.

Fuzzy Control Process

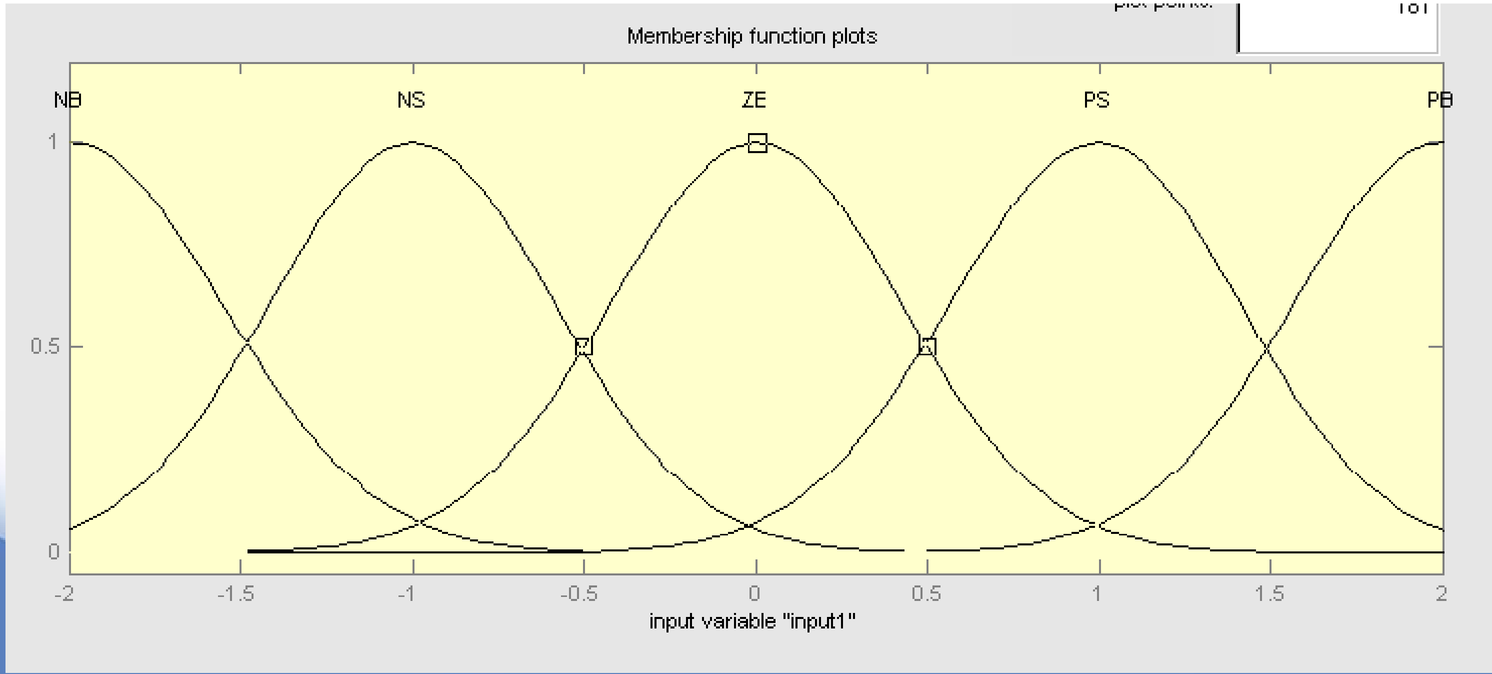
A fuzzy control consists respectively of **fuzzification**, **rule base**, **inference mechanism** and **defuzzification**,



Fuzzification

A single crisp input value can take on more than one linguistic value if the domains of membership function overlap. This process is called fuzzification.

Membership Function



Rule Base

A fuzzy system is characterized by a collection of linguistic statements based on expert knowledge. The linguistic statements are usually in the form of IF-THEN rule

IF stress is high THEN increase thickness
IF stress is low THEN reduce thickness

Inference & defuzzification

Inference

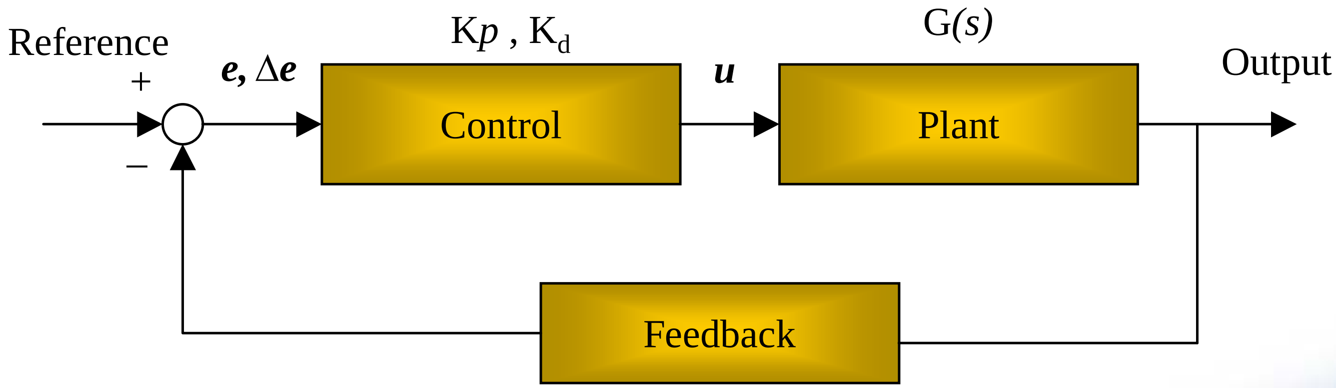
Mamdani’s method

Defuzzification

The widely used COA strategy generates the center of gravity of the possibility distribution of a control action

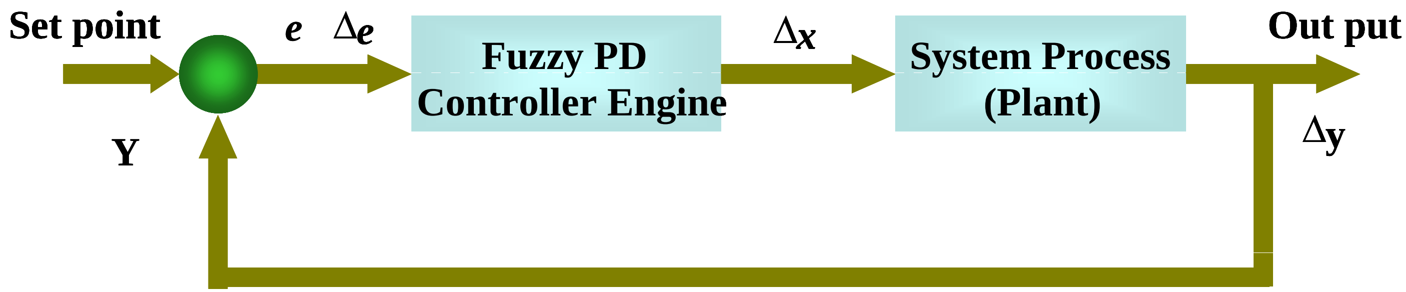
PD Control

Proportional-derivative (PD) control is a very popular control scheme in industry due to its simple structure and easy tuning. For many simple processes, PD control can usually obtain satisfactory control performance



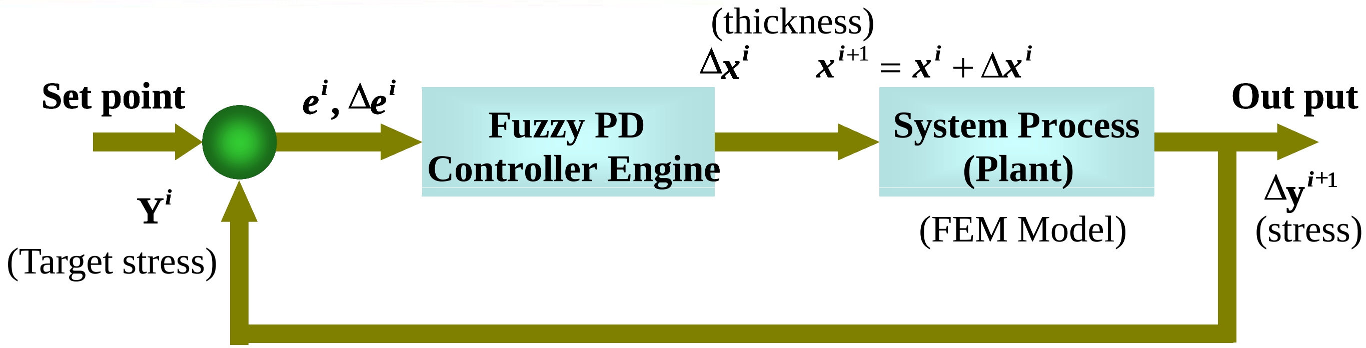
$$u = K_P e + K_d \frac{de}{dt}$$

Fuzzy PD Control



		e				
		NB	NS	ZE	PS	PB
△*e*	NB	NB	NB	NS	NS	ZE
	NS	NB	NS	NS	ZE	PS
	ZE	NS	NS	ZE	PS	PS
	PS	NS	ZE	PS	PS	PB
	PB	ZE	PS	PS	PB	PB

Fuzzy PD Control Optimization Algorithm



$$\min f = \left(\sum_{k=1}^{n} \left(y_k - Y_k \right)^2 \Big/ n \right)^{0.5}$$

$$e_i = y_i - \mathrm{Y} \qquad \Delta e_i = (y_i - \mathrm{Y}) - (y_{i-1} - \mathrm{Y})$$

n: control points

- The iterative process continues until the predefined convergence criterion is reached.

Rule Base for Fuzzy PD Control Optimization

In axis symmetric shell structures, the relation between stress and thickness

Rule 1. IF stress is high THEN increase thickness

Rule 2. IF stress is low THEN reduce thickness

Fuzzy PD control

Rule 3. IF stress is high AND stress is decreasing THEN increase thickness softly
Rule 4. IF stress is high AND stress is increasing THEN increase thickness strongly
Rule 5. IF stress is low AND stress is increasing THEN decrease thickness softly
Rule 6. IF stress is low AND stress is decreasing THEN decrease thickness strongly

Rule 3 and Rule 5 try to **prevent overshoot**

Rule 4 and Rule 6 try to **increase the converging speed**

Rule Base for Fuzzy PD Control Optimization

		e(the difference between the stress and the target stress)		
		$e > 0$ （stress too high）	ZE	$e < 0$ （stress too low）
		$\triangle x > 0$ (Increase thickness)		$\triangle x < 0$ (decrease thickness)
$\triangle e$	$\triangle e > 0$ (stress increasing ）	Strong output	ZE ZE	Soft output
	ZE	Normal output	ZE	Normal output
	$\triangle e < 0$ （stress decreasing)	Soft output	ZE ZE	Strong output

		e				
		PB	PS	ZE	NS	NB
$\triangle e$	PB	PB	PB	ZE	NS	NS
	PS	PB	PS	ZE	NS	NS
	ZE	PB	PS	ZE	NS	NB
	NS	PS	PS	ZE	NS	NB
	NB	PS	PS	ZE	NB	NB

Rule Base for Fuzzy PD Control Optimization

Quantization Table

Quantized Level	e	$\triangle e$	$\triangle x$
2	Target stress	Target stress/2	50% of initial thickness
1	Target stress/2	Target stress/4	50% of initial thickness/2
0	0	0	0
-1	-Target stress/2	-Target stress/4	-50% of initial thickness/2
-2	-Target stress	-Target stress/2	-50% of initial thickness

Case 1: cylinder-cone intersection problem

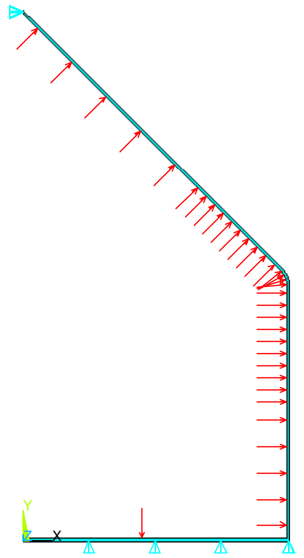
Objective function

$$\min f = \left(\sum_{k=1}^{n} (y_k - Y_k)^2 \Big/ n \right)^{0.5}$$

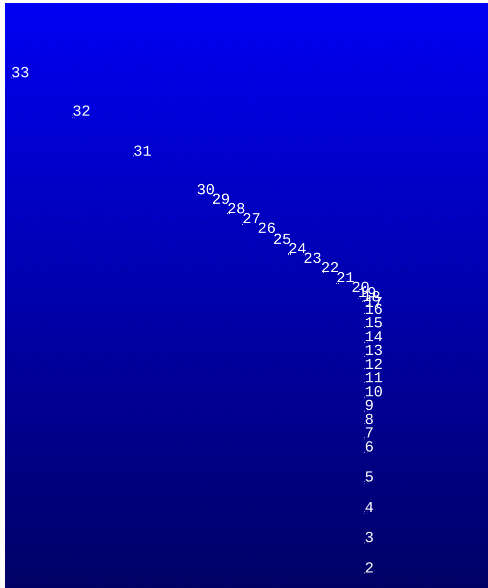
Target stress :10 MPa

Internal pressure : 0.2MPa

Initial thickness: 10 mm



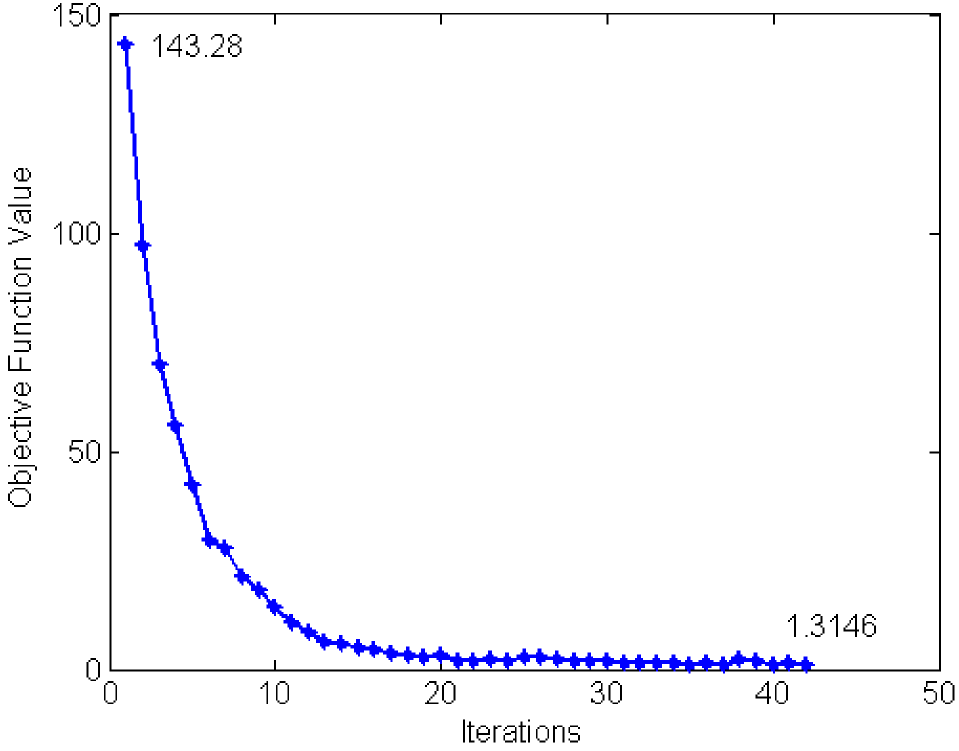
Boundary Conditions



35 control points

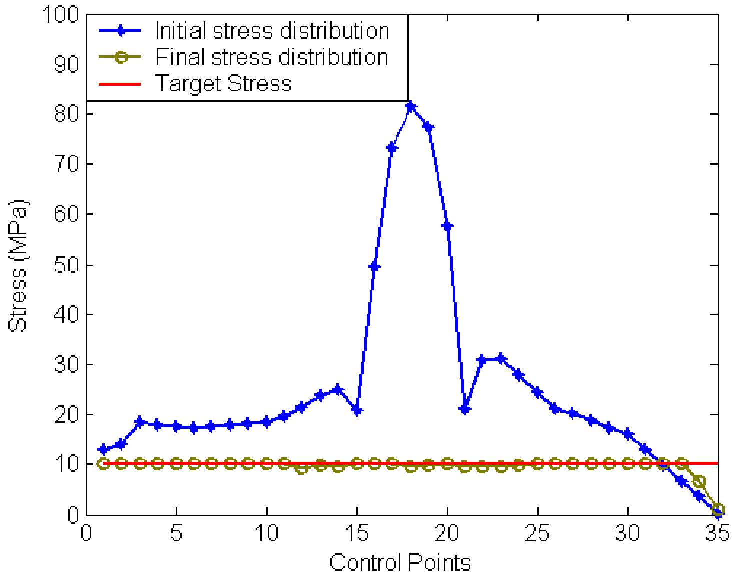
Case 1: cylinder-cone intersection problem

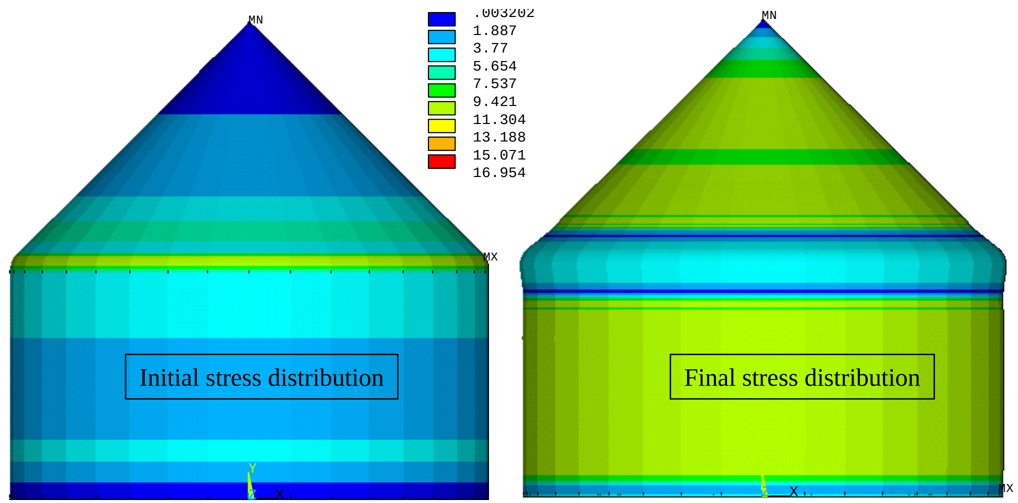
Objective Function



Case 1: cylinder-cone intersection problem

Stress distribution

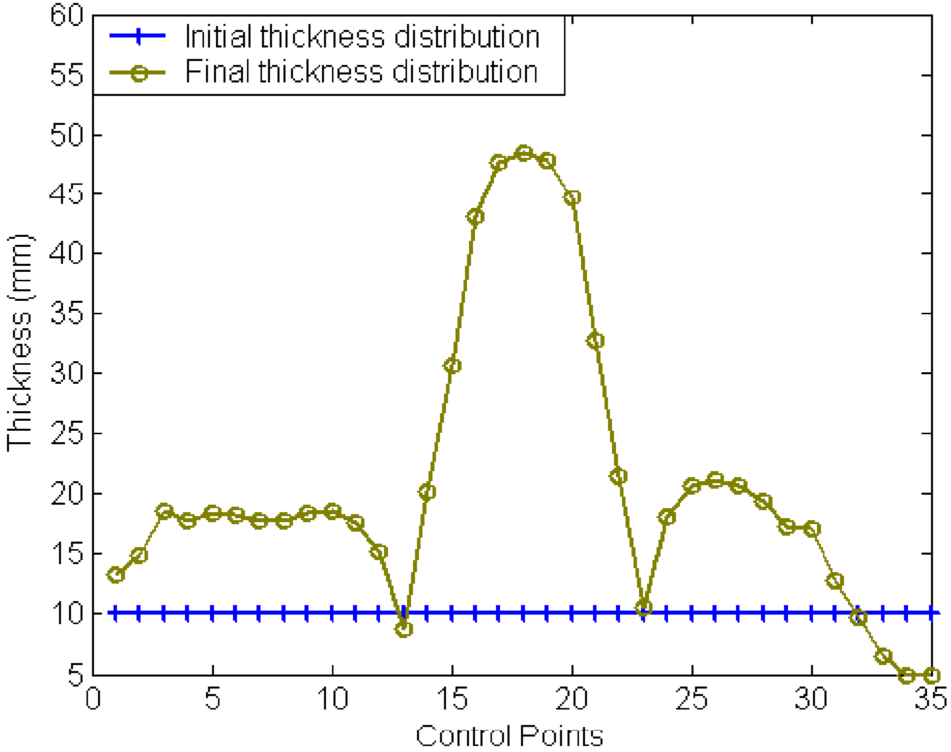


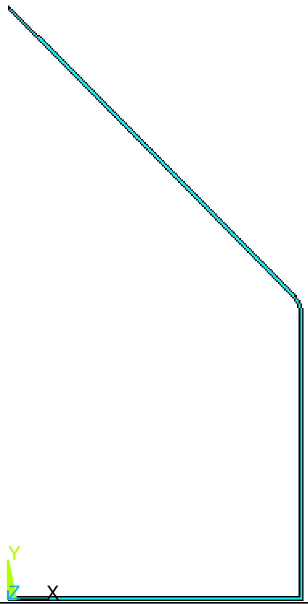


The larger of the inside and outside diameters von Mises stress is used in the iteration.

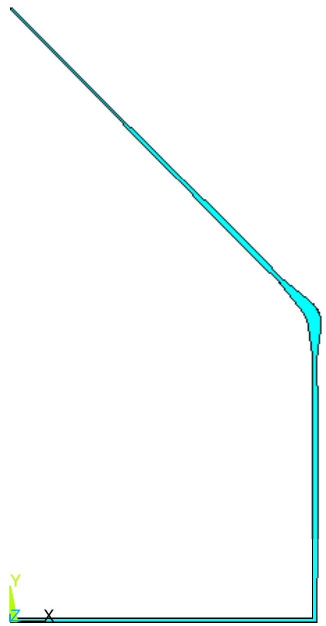
Case 1: cylinder-cone intersection problem

Thickness distribution





Initial thickness distribution



Final thickness distribution

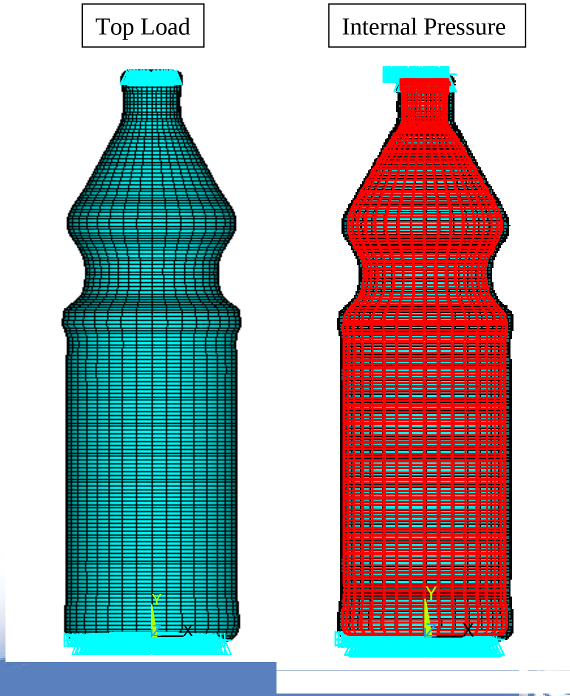
Case 2: a bottle shape problem

Objective function

$$\min \ f = \left(\sum_{k=1}^{n} (y_k - Y_k)^2 \Big/ n \right)^{0.5}$$

y_k is the Max. ($\sigma_{topload}$, $\sigma_{pressure}$) on the k-th control point

Y_k is the corresponding target stress :16.5 Mpa



Top load : -5mm

Internal pressure : 0.785MPa(110psi)

Target stress: 16.5 Mpa

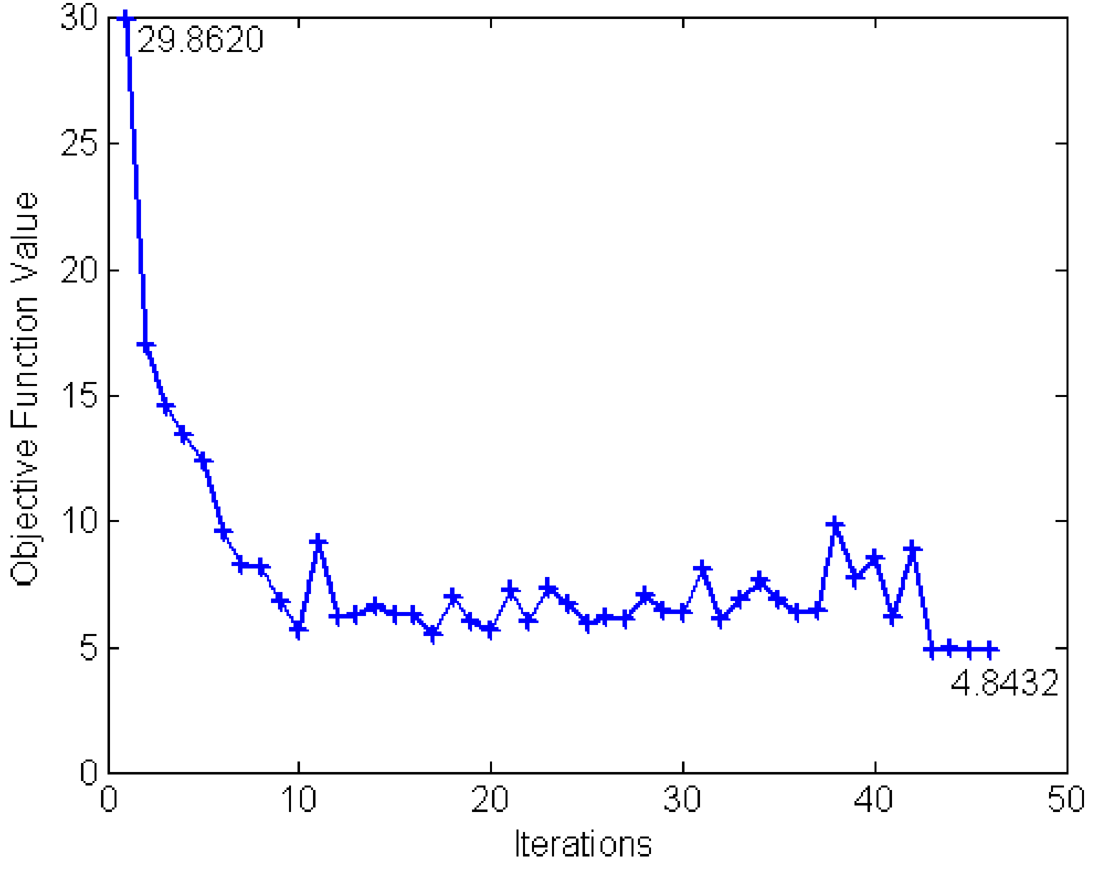
Initial thickness: 2 mm

Maximum allowable: 4 mm

Minimum allowable: 1 mm

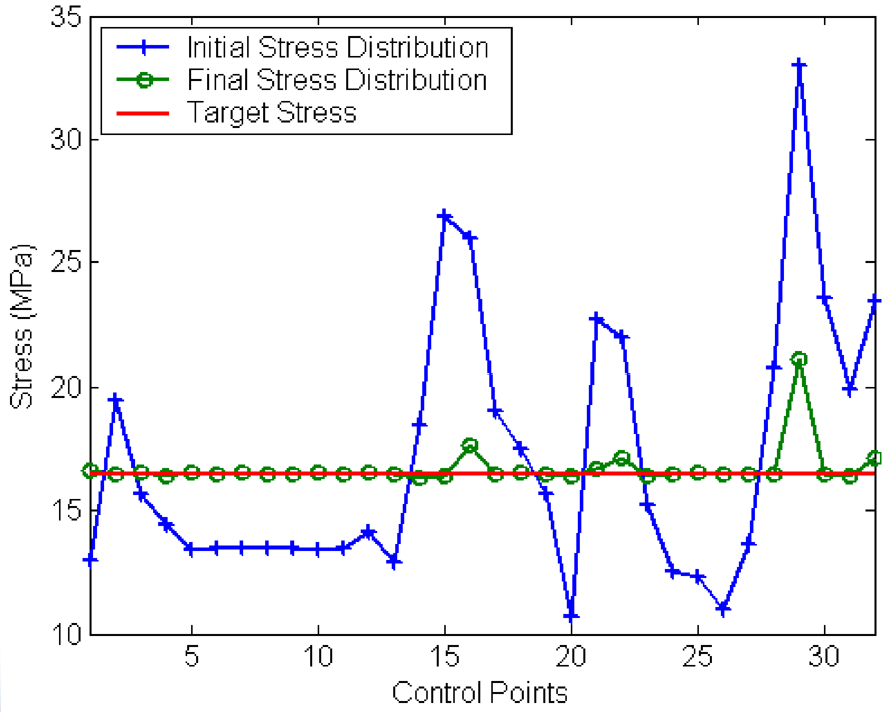
Case 2: a bottle shape problem

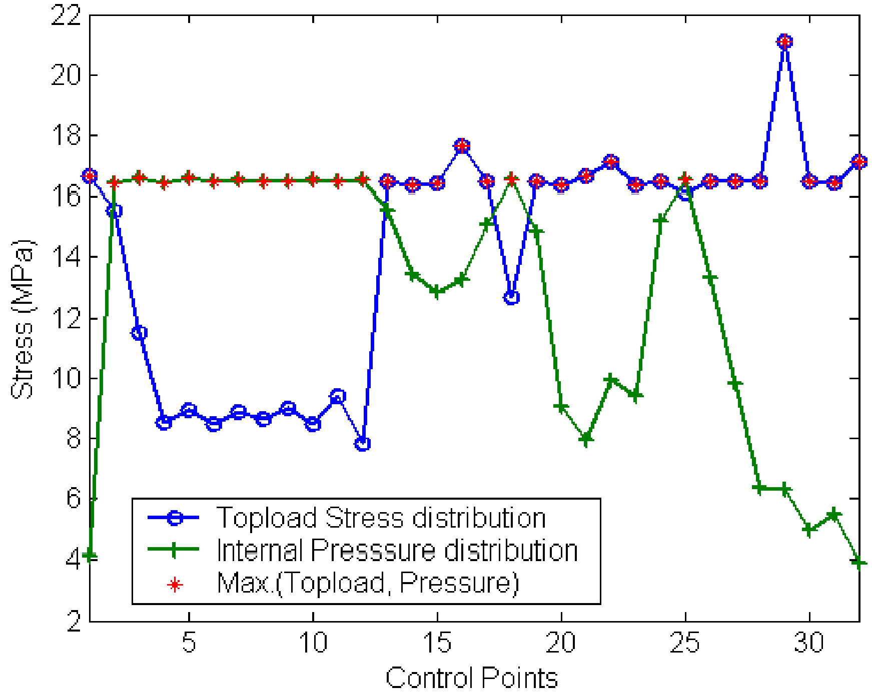
Objective function history



Case 2: a bottle shape problem

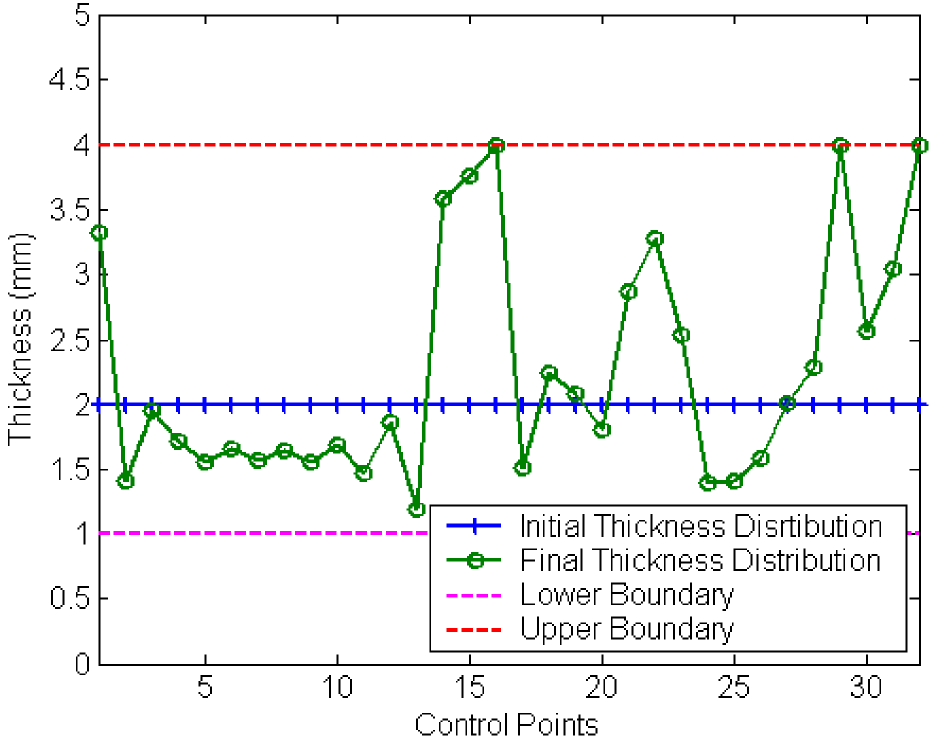
Stress distribution





Case 2: a bottle shape problem

Thickness distribution



Conclusion

- The fuzzy PD control optimization algorithm is **zero-order** optimization method that requires only stress values along the shell, without sensitivity analysis.

- The procedure presented in this paper provide a fuzzy PD controller method and tool to efficiently aid in the design of shell structures.

- This investigation has displayed that fuzzy PD control method are possible to instead of using purely numerical information to obtain the new design point in the next iteration.

- Engineering knowledge and expert experience process can be modeled in the PD controller.