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OPTIMIZATION AND VALUE ANALYSIS OF A PRESSURE VESSEL SHELL

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Abstract

Traditional methods of cost reduction are unable to achieve significant improvement in product costs influenced by design. Creative ideas can be generated using value analysis. Comparison of different methods is shown by a case study regarding a pressure vessel shell.

Keywords: value analysis, cost reduction, pressure vessel shell.

Introduction

Optimization is a basic principle of the theory of economic planning, although people generally do not endeavour an optimum solution but rather only a satisfactory one. The idea of economic optimization is generated from demand of rational allocation of scarce resources, thus optimum and constraints are interdependent variables. If resources can replace each other without any limitation then money is the resource in shortage, and a structure of determined function is optimum if its costs are minimum. However, for a given manufacturing system, and during a not very long time, the resources — materials, labour and instruments — cannot replace each other without limitations, and in this case the maximum of profit is not represented for the manufacturer by a structure with minimum costs.

In the course of an earlier work [3], we examined the influence of resource shortages on the optimum of the structure. By making use of some of the results of our earlier analysis, the present article aims to examine the interrelationship between function and value. We compare the results of optimization with those of value analysis.

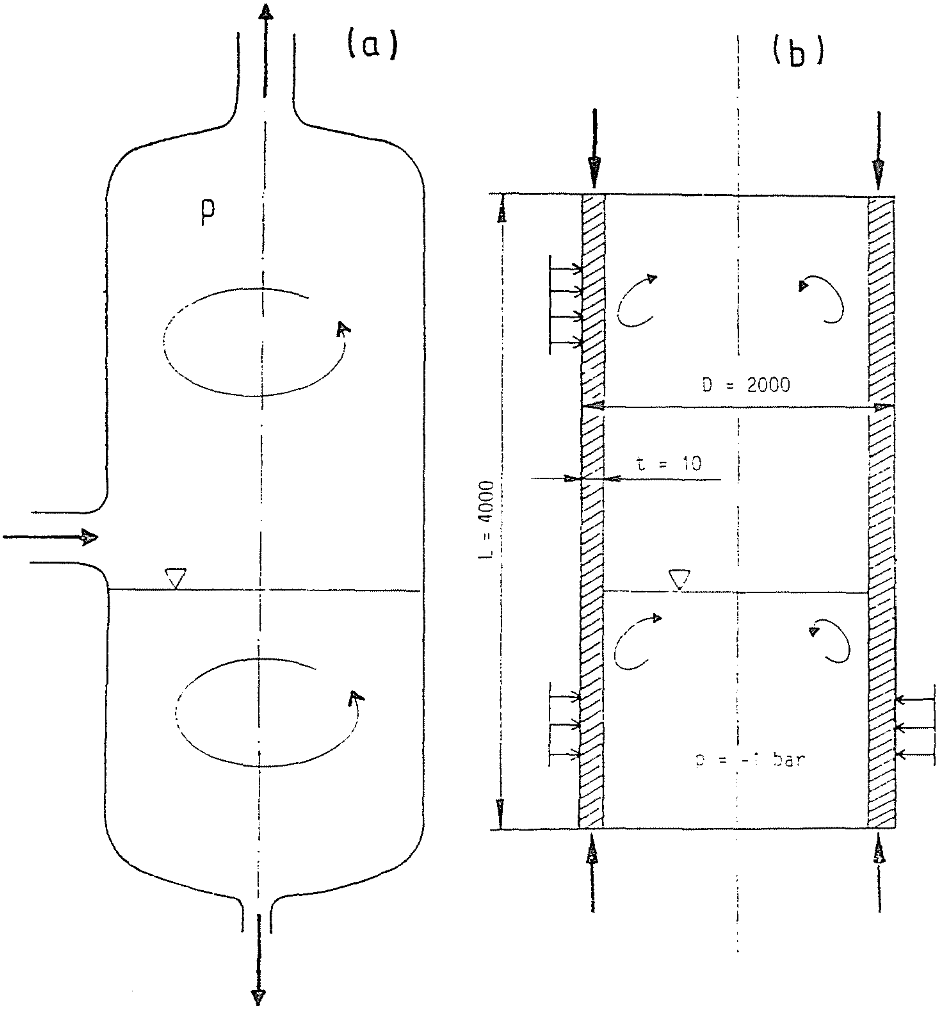

Fig. 1. Pressure vessel. (a) Functional sketch, (b) Sizes and loads of cylindrical shell

A Case Study

Let us examine the pressure vessel shown in *Fig. 1,* which is used for the separation of steam (vapour) and liquid. The diameter, height and pressure of the medium is determined by the technology. The vessel is constructed from high alloy chrome-nickel steel. The wall thickness used until now was $t = 10\,\mathrm{mm}$. It turned out that the installation is too expensive and therefore a minimum 15% cost reduction is necessary. For sake of simplicity we considered only the cylindrical shell (see *Fig. 1b*). Its calculated direct production cost is 650 units (1 unit equals 1000 HUF).

'Traditional' Solution

It is well known that stability of vessels under external pressure with stiffening rings is higher than that of simple cylindrical shells. Let us decrease the shell thickness by 20%, that is to 8 mm, following the calculations indicated by standards [2] and apply 2 stiffening rings (see *Fig. 2*) which are also made of alloyed steel. So we are able to reduce the costs of the vessel shell to 548 units. Since $(650 - 548) : 650 = 0.157$, we can state that we have just achieved the desired cost reduction.

Further strength calculations have shown that 6 mm thickness should be enough, too, but only with the application of 3 stiffening rings. This time the costs become 391 units, which means a 40% decrease. Thus we have even exceeded the plan. The designer has no time available for further studies.

If the strength calculations are made with an adequate software, the designer may examine more variants (see *Table 1*). It may be seen from the table that if the shell thickness is $t = 10$ mm, there is no need for stiffening rings. However, if shell thickness is decreased to $t = 2$ mm, then 33 stiffening rings are needed, each placed at a distance of $l = 120$ mm one from another. The results verify the original decision of the designer, who decided to go for the 6 mm wall thickness. If one were to apply 5 or 9 reinforcing rings, too many weldings would be needed. Due to lack of other necessary data, the choice of wall thicknesses below 6 mm would carry a high risk factor.

Table 1

Structural variants of cylindrical shell stiffened by rings

$p = 1$ bar external pressure, t — thickness of internal shell, n — number of rings, l — distance between stiffening rings

t [mm]	2.0	2.5	3.0	3.5	4.0	5.0	6.0	7.0	8.0	10.0
n [pc]	33	22	17	12	9	5	3	2	1(2)	0
l [mm]	120	177	245	339	440	734	1100	1470	2000	—

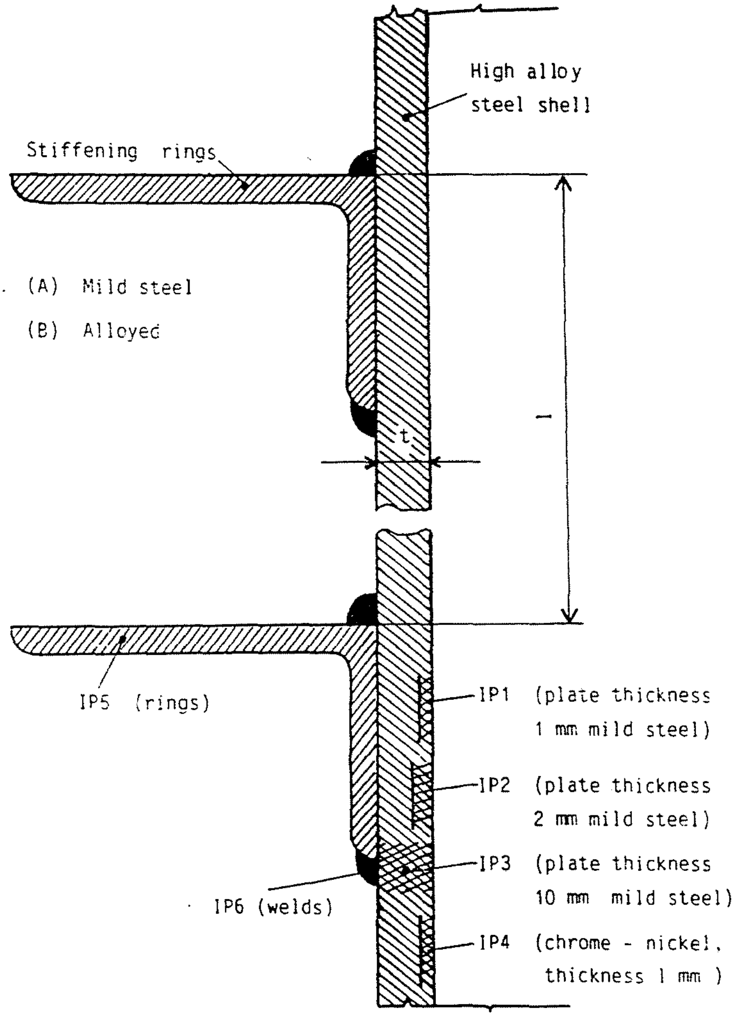

Fig. 2. Stiffened cylinder.
(A) Combined version, high alloy steel shell and mild steel rings,
(B) Shell and rings are made all of high alloy steel

Optimization

The mentioned example was calculated in details with real data (*Fig. 3*). We have determined the material requirements (a), the necessary working time (c), the material costs (b) and finally the labour costs, including social security charges (d). We took into consideration two times two alternatives for the costs:

(A) Shell made of high alloy steel, stiffening rings of mild steel (Combined version)
(B) Shell and rings are made all of high alloy steel (Alloyed version), and
(a) Low labour costs
(b) High labour costs (5 times higher than *a*)

From *Fig 3a–d* we may see the followings:

(a) The total mass has a minimum at a wall thickness of 4 mm (*Fig 3a* curve (2)), the mass of the internal shell (1) increases proportionally with the wall thickness.
(b) The material cost of the structure from homogeneous materials (B) has a minimum at the minimal mass. The combined structure (A) gets cheaper as the internal shell of alloyed steel gets thinner. Above 6 mm wall thickness the costs of the internal shell are predominant, the curves (A) and (B) overlap.
(c) When the wall thickness goes below 6 mm, the labour time increases rapidly, due to the necessity of applying more and more stiffening rings (see *Table 1* too).
(d) The labour costs are not significant in the 6–10 mm region, if it is compared with the cost of the materials: 10–50 vs. 400–600.

In *Fig. 4* we show all the direct costs, in function of the wall thickness, using four combinations of the structural materials and levels of the salaries. The four variants lead to four different optimums (see *Table 2*).

Table 2

Optimal wall thicknesses and the associated direct costs

	Variant	Thickness [mm]	Direct costs
1	Aa	2.5	241.0
		3.0	256.0
		4.0	290.0
2	Ab	3.5	362.0
		4.0	365.0
3	Ba	4.0	372.0
4	Bb	4.0	446.0
5	Aa	6.0	548.0
6	Bb	6.0	532.0

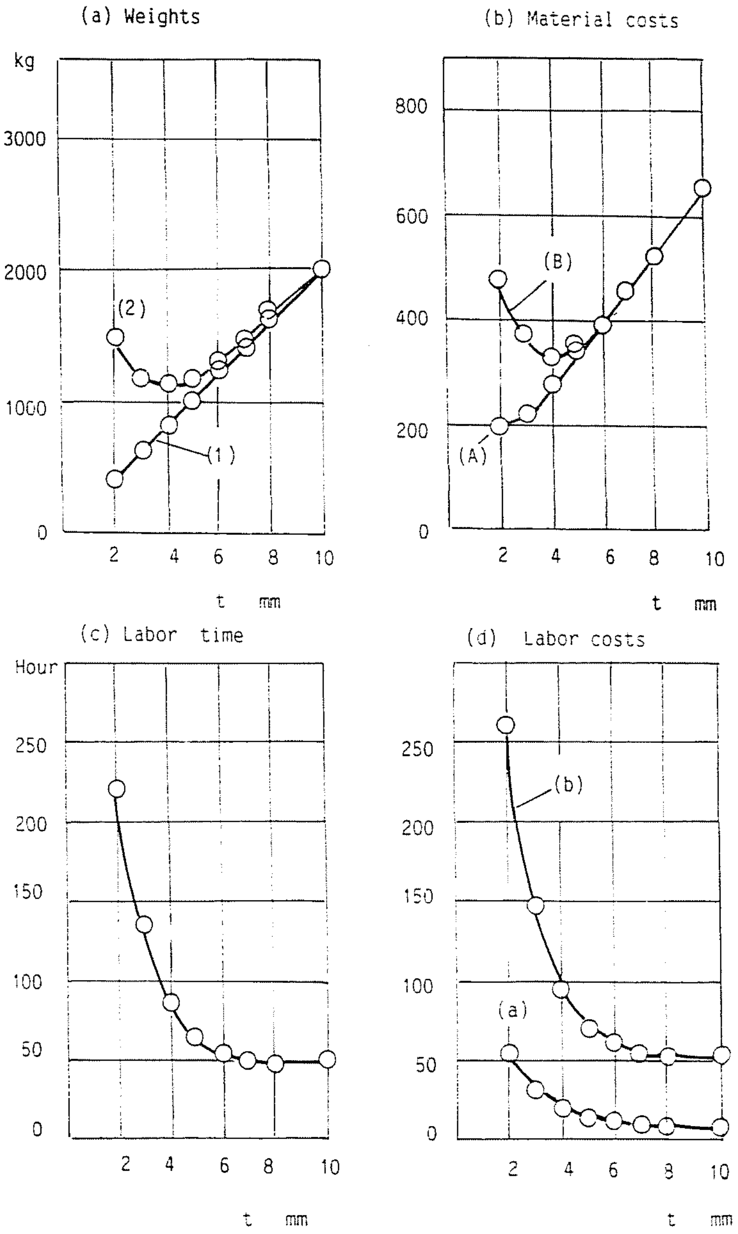

Fig. 3. Expenses and costs (in thousand HUF)
(a) Mass of vessel, (1) shell alone, (2) shell with rings, (b) Material costs, (A) combined, (B) alloyed steel, (c) Labour time, (d) Labour costs, (a) low, (b) high.

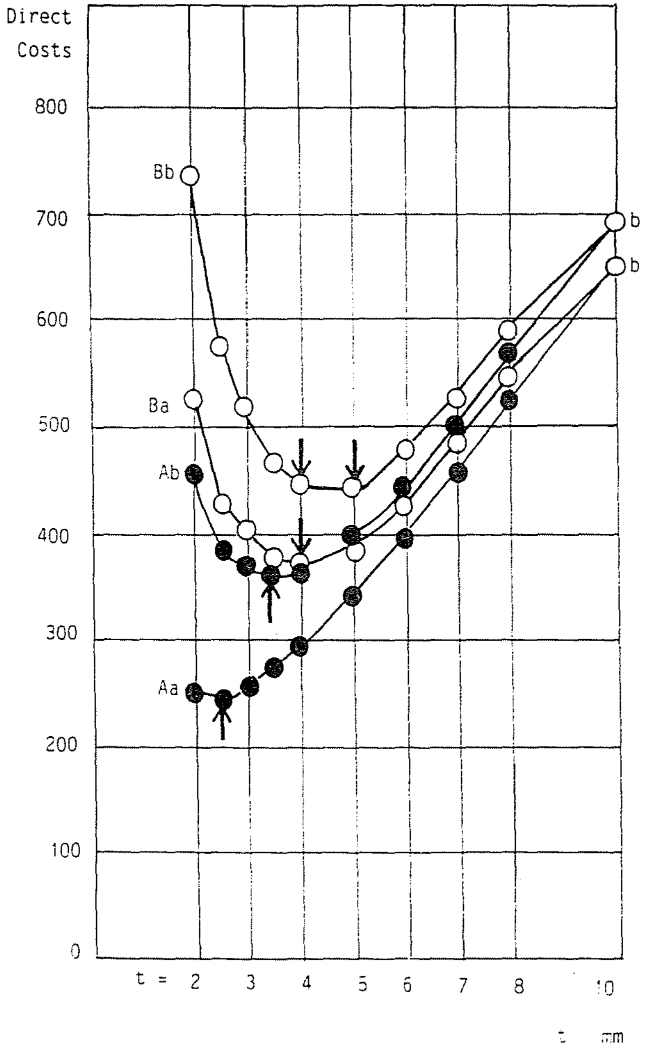

Fig. 4. Direct costs.
Aa – combined version, low labour costs, Ab – combined version, high labour costs, Ba – alloyed version, low labour costs, Bb – alloyed version, high labour costs

In rows 5–6 of *Table 2* we included the costs calculated in the traditional manner, that is associated to a non-optimised wall thickness. When applying wall thicknesses closer to optimal, the cost decrease is significant, i. e. in the case of variant Aa it reached about 50%.

Value Analysis

The traditional cost reduction method which is based on the existing costs of a product, is unable to find all the possibilities existing in the system. That is why it is necessary to develop a creative method which will yield better results. One of the classics of value analysis is MILES [1]. We do not detail the procedure itself, however, we summarized the main concepts in *Fig. 5.* The strength of the method lies in the fact that the costs are not derived from the existing product but rather from a function originating in the requirements of the customer.

According to MILES, the value of the function is the smallest cost with which the function can be performed. If the functions are independent from one another the total function value of the product would be the sum of the individual function values. This is then compared to the costs of the present product. If the functions are not independent, the product is constructed gradually and the function value is defined by the added value adding a new function to the product. The method is illustrated in the already discussed case (*Table 3*)

(a) We examine the ways to fulfil a function individually and we determine the associated costs. These are the separated function values (see *Table 3,* row 2).

(b) We construct the product in such a way that we add to the already existing parts new elements or properties, but to the costs we add only the increase. This is the additional function value, *Table 3,* row 3.
In the case of independent functions the result is identical, while in the case of interrelated functions it is different.

(c) After this stage we go through the functions (F1 ... F4) and product parts (IP1 ... IP4) and we distribute the additional function values among the individual subfunctions, see rows 4–7.
Fig. 6 shows in a very simplified manner the subfunctions of the examined product, i. e. pressure vessel shell. The product parts are also marked in *Fig. 2.*
F1 'Assigns Space' — 'IP1'
This is the most important subfunction. From calculations of chemical engineering or from experience we know the geometrical requirements necessary for the separation of a medium of a given composition and

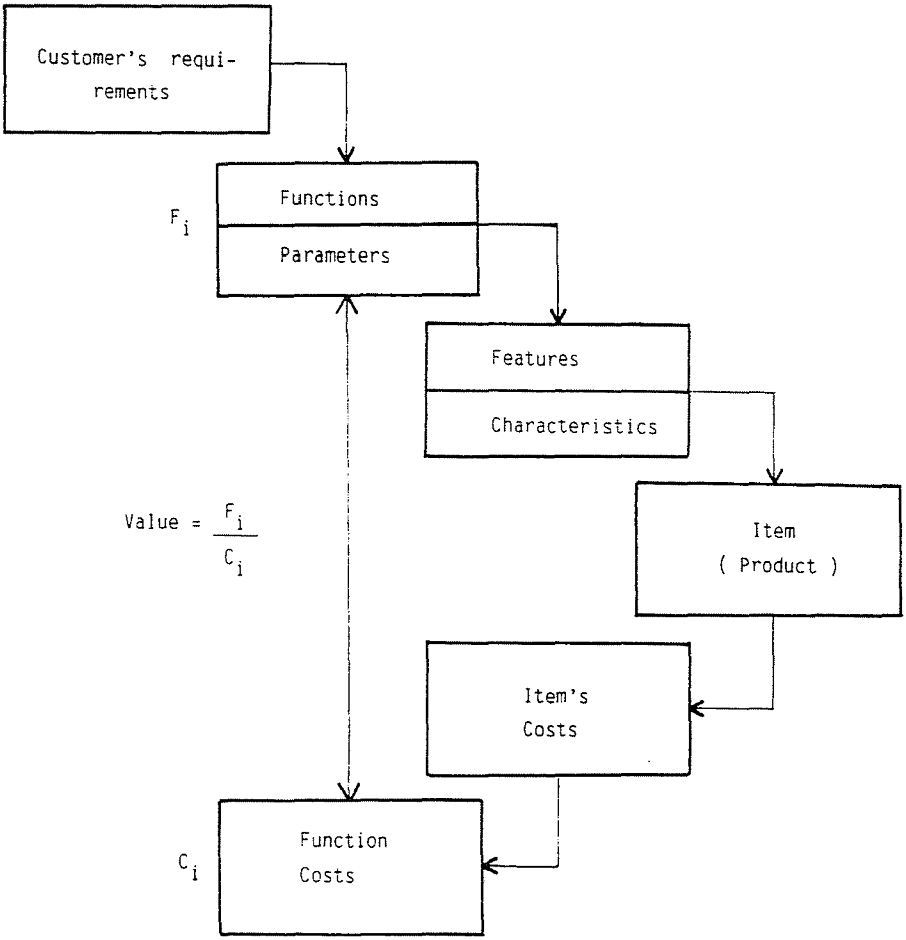

Fig. 5. Basic concepts of value analysis

quantity (see *Fig. 1*). The space could be assigned from the environment even by several methods. Let us assume that a 1 mm thick mild steel plate is satisfactory. The costs of this are 10 units (see *Table 3,* row 2 and column 2). Since this a part of the shell is part of the whole and it participates in functions F2 and F3 but not in F4, its associated cost is distributed between F1 – F2 – F3.

F2 'Limits Medium' — 'IP2'

Because of the dynamic effects of the medium, a shell with 1 mm wall thickness is not sufficient. Let be $t = 2$ mm, having a cost 20. Naturally, this shell also satisfies F1. In column 3 of the table we included only the increase (row 3, column 3, 10) and we split it between F2 and F3.

F3 'Carries External Pressure' — 'IP3'

We know that an unstiffened steel shell is adequate when wall thickness is 10 mm. The cost is 96, the increase 76. This was obtained by subtracting the costs associated to 2 mm of the shell thickness. This part of the product participates only in F3 (row 6, column 4)

F4 'Prevents Corrosion' — 'IP4'

This function can be satisfied by many materials and coatings. Let us take arbitrarily a 1 mm shell thickness made of alloyed steel. The value is 65 in this case. Since we already have a carbon steel structure, in column 5 only the cost of the alloying elements will determine the increase, that is 65 – 10 = 55 units. This is associated totally to F4.

Table 3
Function value and cost analysis

	1	2	3	4	5	6	7
1	Part of product	IP 1	IP 2	IP 3	IP 4	Total	Total %
2	Separated function value	10	20	96	65	191	—
3	Added function value	10	10	76	55	151	100
4	F_1	2	0	0	0	2	1 .3
5	F_2	3	6	0	0	9	6 .0
6	F_3	5	4	76	0	85	56 .3
7	F_4	0	0	0	55	55	36 .4
8	Function values of product parts	10	10	76	55	151	100 %
9	Costs of existing product	10	65	520	55	650	
10	Unnecessary costs	0	55	444	0	499	

(d) Summing the costs by row and column, we reach the result that the separated function value is equal to 191 units, while the added function value is equal to 151 units. Thus we have achieved the ideal value, towards which one endeavours to tend in the course of cost reduction.

(e) Similarly one could distribute the real costs of the original alloyed steel shell $t = 10$ mm that was discussed in the initial case study and one could then determine the real function costs (see *Table 3,* row 9).

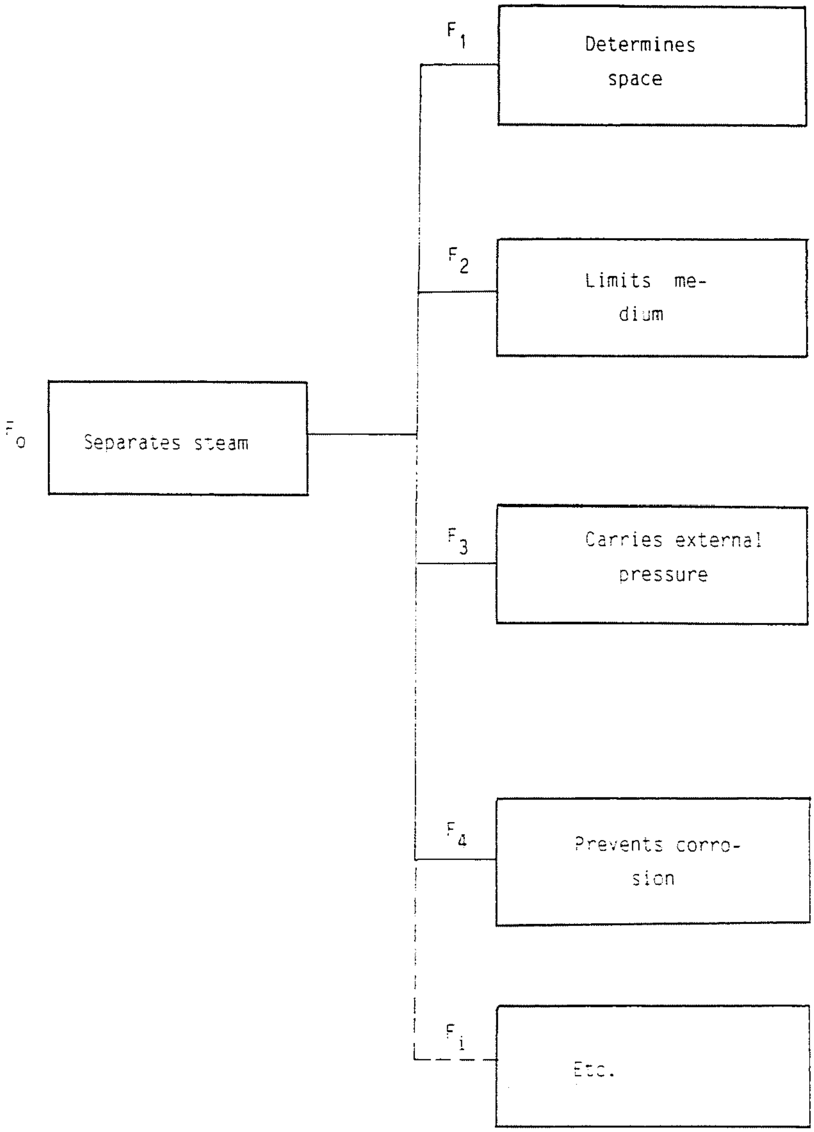

Fig. 6. Simplified function diagram of steam (vapour) separator

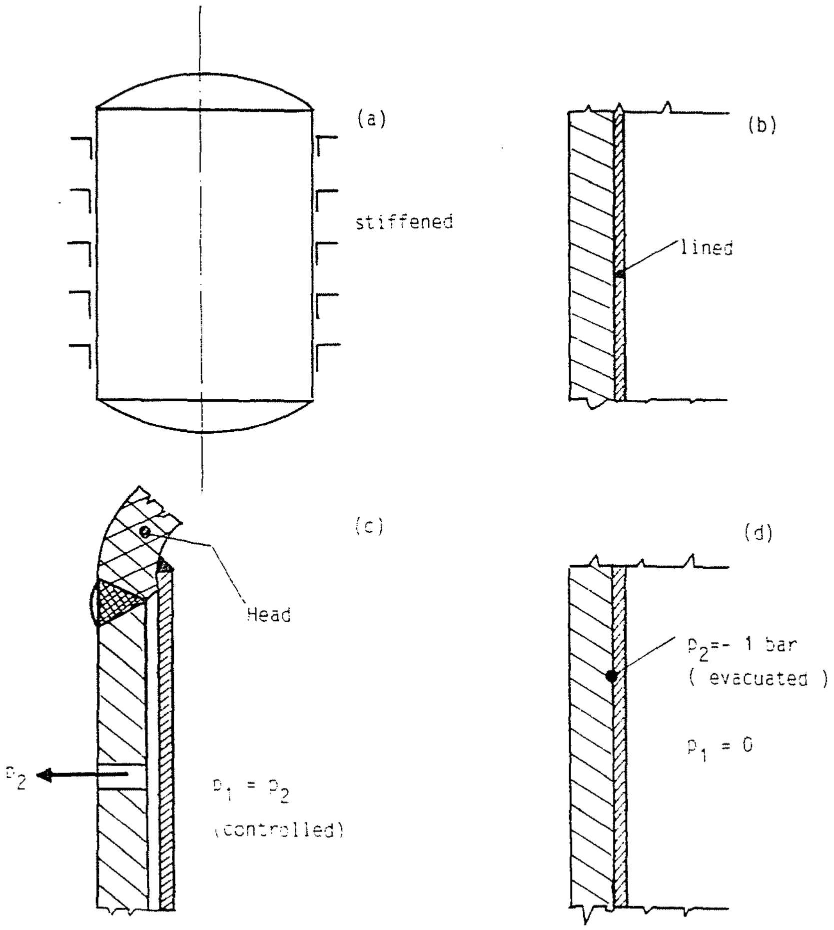

Fig. 7. Creative ideas to improve design.
(a) Optimum stiffening, combined version, (b) Anti-corrosion internal coat, or use of flattened sheet, (c) Load-free anti-corrosion shell, (d) Pre-stressing of the corrosion resistant shell

(f) The comparison of the function values with the real function costs shows the weak points in the product. Let us compare only the total sums (see *Table 3,* column 6):
Function value 151 units (row 8)

Product costs	650 units (row 9)
Unnecessary costs	499 units (row 10)

Weak points of product are IP2 and IP3.

(g) The preferences of the customer should be taken into account, too, but this time we will not discuss it.

Creative Ideas

The absolute optimum obtained in *Table 2* consisted of 241 units. The value analysis shows that this is not yet necessarily the best that can be achieved. In *Fig. 6* we show some ideas of creating new solutions.

Additional Remarks

Our investigation is focused only on one element of the structure. Disregarded conditions may considerably change the design. Thus, if besides the purity of the product one is also interested in the cleanliness of the environment, the rings should be manufactured from chrome-nickel steel. If there are space constraints, it may happen that rings cannot be used. Therefore only the unstiffened high alloy steel shell can be adequate. The resources available also exert an influence, we have discussed this matter in an earlier paper [3].

Value analysis is an analysis in the proper sense of the word. The synthesis of combined structures is best achieved with the Quality Function Deployment (QFD) method [4].

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