RESEARCH ON ULTRASONIC SYSTEM DEVELOPMENT APPLIED IN HOUSEHOLD PRODUCTS CLEANING

IONESCU Cătălin Nicolae[1], POPESCU Laurenţiu[1],
[1] IMST Faculty, Study Programme: Industrial Engineering, 1st year Master
Corresponding author: IONESCU Cătălin Nicolae, e-mail: catalin.ionescu24@gmail.com

Scientific coordinators: Lecturer PhD Eng. Mihaela ULMEANU, Prof. PhD Eng. Ec. Cristian DOICIN

ABSTRACT:
The paper is part of a larger project of the authors and presents the conceptual design of an ultrasonic washing system for small household items embedded in a washing machine. The paper presents the way in which the concepts were generated using various methods and tools to stimulate creativity, such as QFD, the matrix of contradictions, CREAX indicators, the 8 laws of systems evolution, etc. Research will continue in order to establish an optimal concept and detailed design of the ultrasonic system.

KEY WORDS: Ultrasonic cleaning, electro-household, washing machine

1. Introduction

Ultrasonic cleaning was first used industrially and then penetrated into various household applications such as: washing clothes [2, 3], washing small household items [2], washing fruits and vegetables [1], etc. The authors' research address the use of ultrasound in household applications by incorporating such systems as extra-option in usual home appliances, such as washing machines, refrigerators, dishwashers etc. A market study was carried out [4, 5] and all stages of the design were covered – competitive design, functional design, conceptual design, architectural design, detailed design [3, 6]. The underlying phenomenon of ultrasonic cleaning is ultrasonic cavitation. Since the ultrasound spreads over the entire mass of the washing liquid, it is possible to clean in the most difficult places but in contact with the washing fluid. It should be noted that the maximum efficiency of the ultrasonic cleaning process is achieved by heating the wash liquid at an optimum temperature (45-55°C) and the resonance frequencies are between 20 - 120 kHz. Research will continue in order to establish an optimal concept and detailed design of the ultrasonic system embedded into a washing machine.

2. Developing a special ultrasonic cleaning machine

2.1. Functional Design

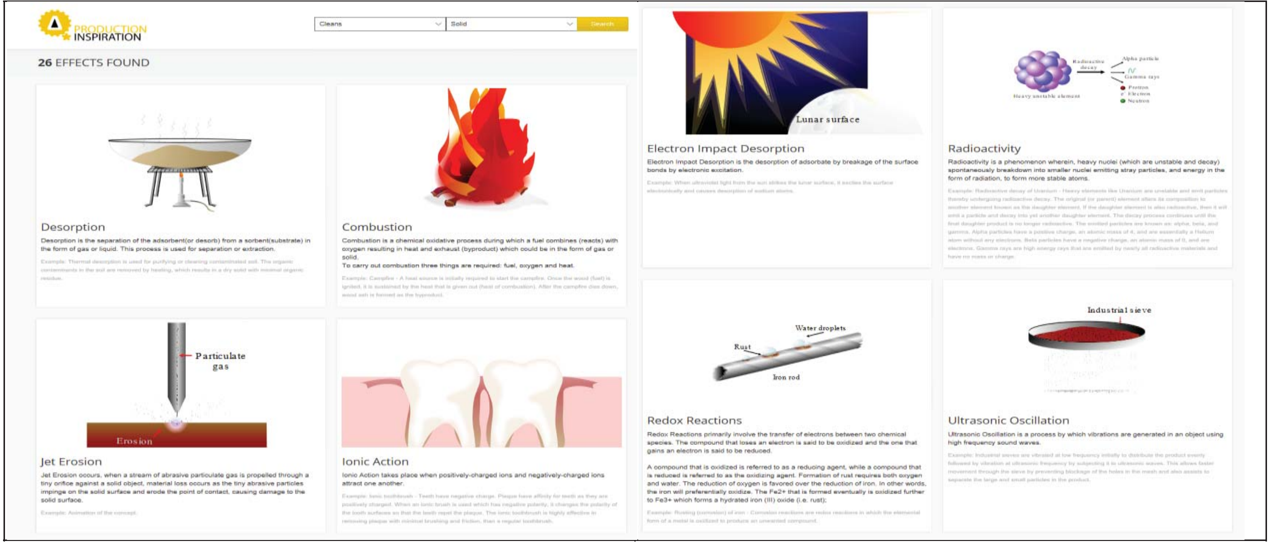
Based on the market study and the establishment of specifications in previous works of the authors [3, 4, 6], the general function, main functions and product sub-functions were established (Table 1).

Table 1. Product functions

Ø = allows washing, squeezing, and drying of laundry and home appliances
Ø1 = Washing of laundry; Ø2 = Squeezing of laundry; Ø3 = Drying of laundry; Ø4 = Refreshing of laundry; **Ø5 = Cleaning other types of household objects;** Ø6 = Fixing on the contact surface and stability; Ø7 = Is ergonomic; Ø8 = Industrial design; Ø9 = Allow easy maintenance; Ø10 = Life and health safety; Ø10 = Life and health safety; Ø11 = Low noise and vibration

For conceptual design, 26 effects for washing and cleaning functions - Ø1 + Ø5, 8 effects for squeezing function - Ø2 and 13 effects for Drying function - Ø3 were analyzed (Table 2) [3, 6].

Table 2 – Possible effects for critical function WASHING AND CLEANING (Extraction [9])



26 EFFECTS FOUND

Desorption

Desorption is the separation of the adsorbent(or desorb) from a sorbent(substrate) in the form of gas or liquid. This process is used for separation or extraction.

Combustion

Combustion is a chemical oxidative process during which a fuel combines (reacts) with oxygen resulting in heat and exhaust (byproduct) which could be in the form of gas or solid.
To carry out combustion three things are required: fuel, oxygen and heat.

Jet Erosion

Jet Erosion occurs, when a stream of abrasive particulate gas is propelled through a tiny orifice against a solid object, material loss occurs as the tiny abrasive particles impinge on the solid surface and erode the point of contact, causing damage to the solid surface.

Ionic Action

Ionic Action takes place when positively-charged ions and negatively-charged ions attract one another.

Electron Impact Desorption

Electron Impact Desorption is the desorption of adsorbate by breakage of the surface bonds by electronic excitation.

Radioactivity

Radioactivity is a phenomenon wherein, heavy nuclei (which are unstable and decay) spontaneously breakdown into smaller nuclei emitting stray particles, and energy in the form of radiation, to form more stable atoms.

Redox Reactions

Redox Reactions primarily involve the transfer of electrons between two chemical species. The compound that loses an electron is said to be oxidized and the one that gains an electron is said to be reduced.

A compound that is oxidized is referred to as a reducing agent, while a compound that is reduced is referred to as the oxidizing agent. Formation of rust requires both oxygen and water. The reduction of oxygen is favored over the reduction of iron. In other words, the iron will preferentially oxidize. The Fe2+ that is formed eventually is oxidized further to Fe3+ which forms a hydrated iron (III) oxide (i.e. rust);

Ultrasonic Oscillation

Ultrasonic Oscillation is a process by which vibrations are generated in an object using high frequency sound waves.

Several effects can be selected as shown in following table 3.

Table 3 Functional effects

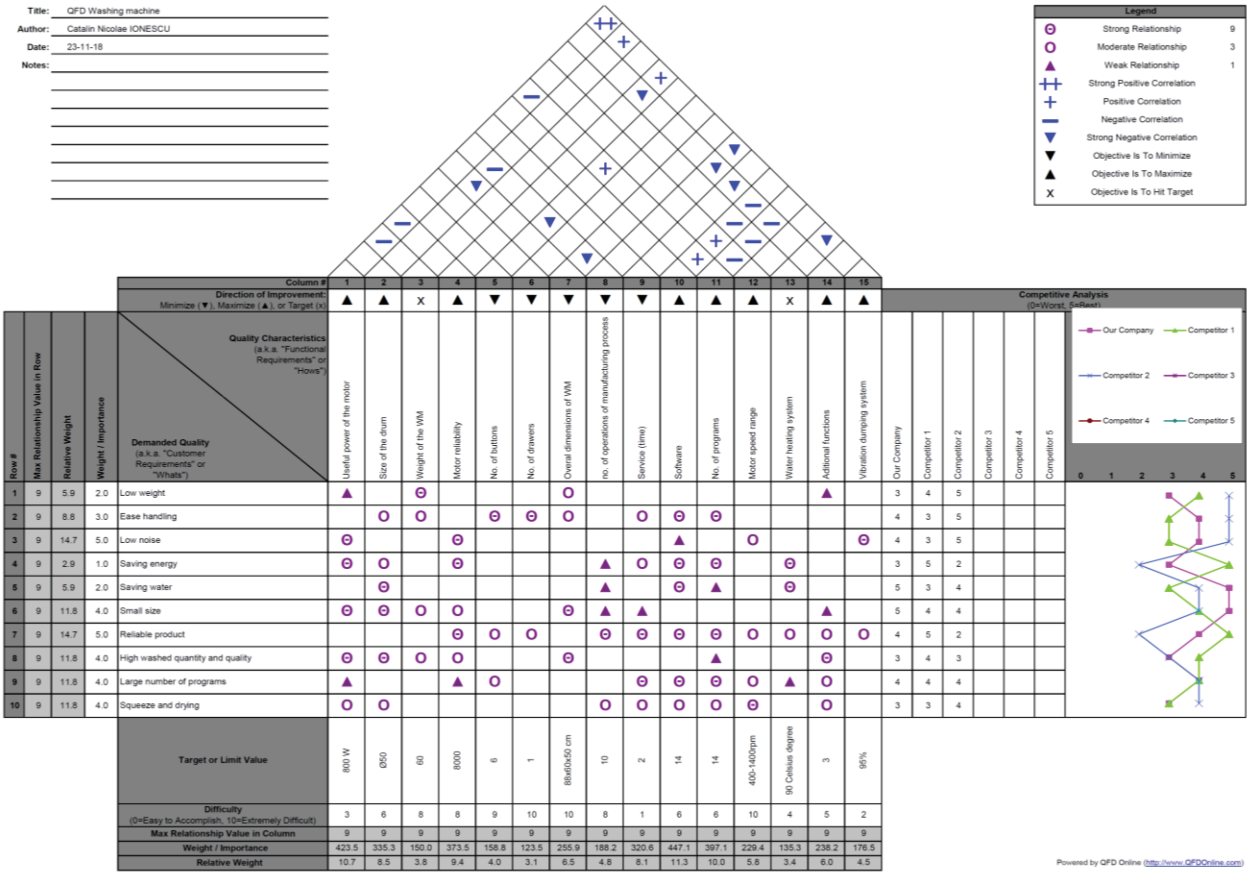
No. function	Name of function	Selected effects
1.	Washing and Cleaning (Ø1 + Ø5)	• Jet erosion; • Redox reactions; • Ultrasonic oscillations, cavitation, acoustic cavitation, acoustic vibrations; • Friction; • Dissolutions; • Electrochemical erosion; • Hydrodynamic; • Thermo-destruction; • Mechanical action; • Adsorption (reverse).
2.	Squeezing (Ø2)	• Absorption (reverse); • Centrifugal separation; • Electro-osmosis; • Ultrasound; • Heating.
3.	Drying (Ø3)	• Acoustic vibrations; • Centrifuge; • Convection; • Ultrasonic drying; • Vacuum drying; • Air impingement.

2.2. Conceptual and architectural Design

Conceptual design is a particularly important stage in the development of each product in which the central element is to generate as many concepts as possible. For this, the R & D team has applied [3, 6] a large number of methods to generate concepts that can be listed: QFD, TRIZ matrix, 40 Inventive principles, 39 TRIZ parameters, 9 screen method, 9 classical ideality indicators, 28 CREAX indicators, physical contradictions, Su-Field analysis, CREAX software [7, 8], the 8 laws of technical systems evolution, analogy (partial solution inspired from patents). In this paper we will present only a few of these.

2.2.1. Concepts generation using QFD (HOQ)–TRIZ–Taguchi and technical contradictions

By developing the correlations established in previous work [3, 6], the washing machine quality house was built, as shown in Figure 1. Some of the contradictions highlighted in the roof of the quality house (negative and strong negative correlations) were analyzed and solved by formulating them as technical contradictions, using the contradictions matrix, the 40 inventive principles and the 39 TRIZ parameters (Table 4). During its evolution, the washing machine improved through consumes reduction (i.e. water, detergent, electricity) together with decreasing of human intervention. For improving a washing machine, the following needs to be analyzed: increasing the washing quantity; increasing the motor power; adding auxiliary functions; reducing the vibrations and noise. The resolution of contradictions and the obtaining of generic solutions (inventive principles) were done both by using the CREAX software program (figure 2) and by using directly the contradiction matrix (table 5).



Title: QFD Washing machine
Author: Catalin Nicolae IONESCU
Date: 23-11-18
Notes:

Legend		
Θ	Strong Relationship	9
O	Moderate Relationship	3
▲	Weak Relationship	1
++	Strong Positive Correlation	
+	Positive Correlation	
−	Negative Correlation	
▼	Strong Negative Correlation	
▼	Objective Is To Minimize	
▲	Objective Is To Maximize	
x	Objective Is To Hit Target	

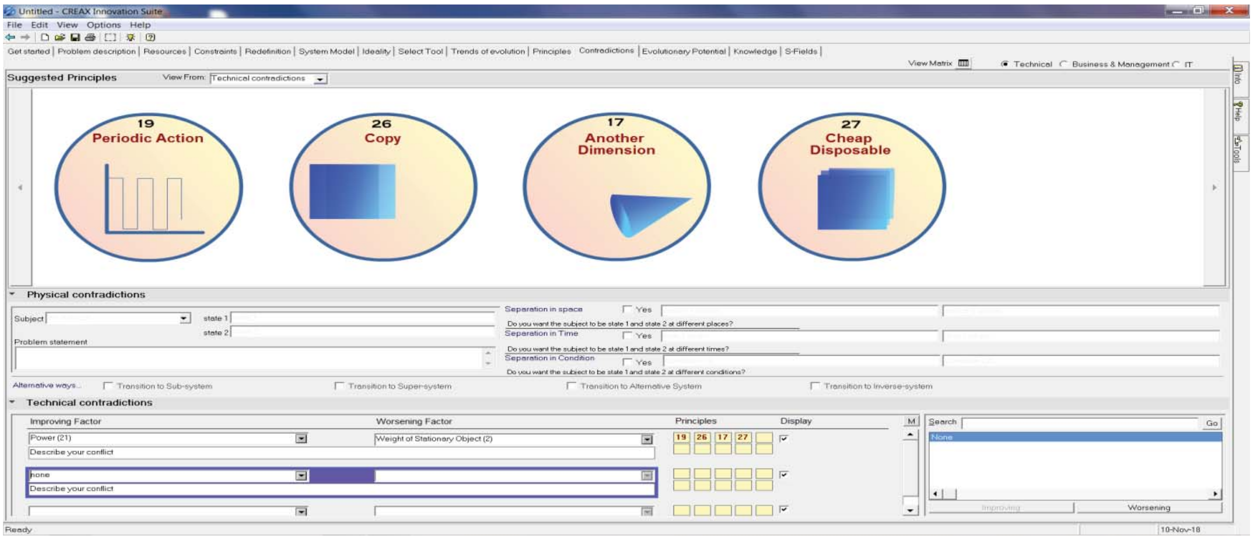
				Column #	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15						
				Direction of Improvement: Minimize (▼), Maximize (▲), or Target (x)	▲	▲	x	▲	▼	▼	▼	▼	▼	▲	▲	▲	x	▲	▲	Competitive Analysis (0=Worst, 5=Best)					
Row #	Max Relationship Value in Row	Relative Weight	Weight / Importance	Quality Characteristics (a.k.a. "Functional Requirements" or "Hows") Demanded Quality (a.k.a. "Customer Requirements" or "Whats")	Useful power of the motor	Size of the drum	Weight of the WM	Motor reliability	No. of buttons	No. of drawers	Overal dimensions of WM	no. of operations of manufacturing process	Service (time)	Software	No. of programs	Motor speed range	Water heating system	Aditional functions	Vibration dumping system	Our Company	Competitor 1	Competitor 2	Competitor 3	Competitor 4	Competitor 5
1	9	5.9	2.0	Low weight	▲		Θ				O							▲		3	4	5			
2	9	8.8	3.0	Ease handling		O	O		Θ	Θ	O		O	Θ	Θ					4	3	5			
3	9	14.7	5.0	Low noise	Θ			Θ						▲		O			Θ	4	3	5			
4	9	2.9	1.0	Saving energy	Θ	O		Θ				▲	O	Θ	Θ		Θ			3	5	2			
5	9	5.9	2.0	Saving water		Θ						▲		Θ	▲		Θ			5	3	4			
6	9	11.8	4.0	Small size	Θ	Θ	O	O			Θ	▲	▲					▲		5	4	4			
7	9	14.7	5.0	Reliable product				Θ	O	O		Θ	Θ	Θ	Θ	O	O	O	O	4	5	2			
8	9	11.8	4.0	High washed quantity and quality	Θ	Θ	O	O			Θ				▲			Θ		3	4	3			
9	9	11.8	4.0	Large number of programs	▲			▲	O				Θ	Θ	Θ	O	▲	O		4	4	4			
10	9	11.8	4.0	Squeeze and drying	O	O						O	O	O	O	Θ		O		3	3	4			
				Target or Limit Value	800 W	Ø50	60	8000	6	1	88x60x50 cm	10	2	14	14	400-1400rpm	90 Celsius degree	3	95%						
				Difficulty (0=Easy to Accomplish, 10=Extremely Difficult)	3	6	8	8	9	10	10	8	1	6	6	10	4	5	2						
				Max Relationship Value in Column	9	9	9	9	9	9	9	9	9	9	9	9	9	9	9						
				Weight / Importance	423.5	335.3	150.0	373.5	158.8	123.5	255.9	188.2	320.6	447.1	397.1	229.4	135.3	238.2	176.5						
				Relative Weight	10.7	8.5	3.8	9.4	4.0	3.1	6.5	4.8	8.1	11.3	10.0	5.8	3.4	6.0	4.5						

Powered by QFD Online (http://www.QFDOnline.com)

Figure 1. House of Quality for washing machine

Table 4

Contradiction No. (TC)	Improving parameter			Worsened parameter			
	Parameter name	Improving desired direction/ Taguchi Type	TRIZ Equivalent Parameter (P1…P39)	Parameter Name	Improvement Direction Taguchi Type	Unwanted effect	TRIZ Equivalent Parameter (P1…P39)
1	Washed quantity	↑ GTB	P26. Quantity of substance	WM overall dimensions	↓ STB	Increasing	P8. Volume of stationary object
	TC1. WHEN WASHED QUANTITY IS IMPROVED/INCREASED (P26), THE GENERAL DIMENSIONS OF THE WASHING MACHINE ARE WORSENED/INCREASED (P8).						
2	Motor power	↑ GTB	P21. Power	WM weight	↓ STB	Increasing	P2. Weight of stationary object
	TC2. WHEN MOTOR POWER IS IMPROVED/INCREASED (P21), THE WEIGHT OF THE WASHING MACHINE IS WORSENED/INCREASED (P2).						
3	Increasing no. of functions	↑ GTB	P36. Device complexity	Reliability	↑ GTB	Decreasing	P27. Reliability
	TC3. WHEN NO. OF FUNCTIONS IS IMPROVED/INCREASED (P36), THE RELIABILITY OF THE WASHING MACHINE IS WORSENED/DECREASING (P27).						
4	Increasing no. of functions	↑ GTB	P36. Device complexity	The manufacturing process is getting more complicated (Manufacturability)	↑ GTB	Decreasing	P.32. Ease of manufacture
	TC4. WHEN NO. OF FUNCTIONS IS IMPROVED/INCREASED (P36), THE MANUFACTURABILITY OF THE WASHING MACHINE IS WORSENED/DECREASING (P32).						
5	Increasing no. of functions	↑ GTB	P36. Device complexity	The repair process is getting more complicated (Reparability)	↑ GTB	Decreasing	P34. Ease of repair
	TC5. WHEN NO. OF FUNCTIONS IS IMPROVED/INCREASED (P36), THE REPARABILITY OF THE WASHING MACHINE IS WORSENED/DECREASING (P34).						
6	Vibrations reduction	↓ STB	P31. Object-generated harmful factors	The manufacturing process is getting more complicated (Manufacturability)	↑ GTB	Decreasing	P.32. Ease of manufacture
	TC6. WHEN VIBRATIONS ARE IMPROVED/INCREASED (P31), THE MANUFACTURABILITY OF THE WASHING MACHINE IS WORSENED/DECREASING (P32).						



View From: Technical contradictions

Improving Factor: Power (21)

Worsening Factor: Weight of Stationary Object (2)

Principles: 19 26 17 27

Figure 2. Solving contradictions using CREAX software

Table 5

Worsening Feature →		**Weight of stationary object**	**Volume of stationary object**	**Reliability**	**Ease of manufacture**	**Ease of repair**
Improving Feature ↓		**2**	**8**	**27**	**32**	**34**
21	**Power**	**19, 26, 17, 27**	**30, 6, 25**	**19, 24, 26, 31**	**26, 10, 34**	**35, 2, 10, 34**
26	**Quantity of substance/the matter**	**27, 26, 18, 35**	🟥	**18, 3, 28, 40**	**29, 1, 35, 27**	**2, 32, 10, 25**
31	**Object-generated harmful factors**	**35, 22, 1, 39**	**30, 18, 35, 4**	**24, 2, 40, 39**	🟥	🟥
36	**Device complexity**	**2, 26, 35, 39**	**1, 16**	**13, 35, 1**	**27, 26, 1, 13**	**1, 13**

Legend: 🟥 No principles in TRIZ Matrix; xxx It was considered no contradiction for our application

Table 6 presents the solutions specifically obtained by customizing generic solutions.

Table 6

No. of Principles	Appearance frequency	Generic Solutions	Specific (conceptual) solutions
1	5	**1. SEGMENTATION: A.** Divide an object into independent parts; **B.** Make an object easy to disassemble; **C.** Increase the degree of fragmentation or segmentation;	#1. Second drawer
26	5	**COPYING: A.** Replace unavailable, expensive or fragile object with available or inexpensive copies; **B.** Replace an object, or process with optical copies; **C.** If visible optical copies are already used, move to infrared or ultraviolet copies;	# No ideas
35	4	**PARAMETER CHANGES: A.** Change an object's physical state (e.g. to a gas, liquid, or solid); **B.** Change the concentration or consistency ; **C.** Change the degree of flexibility; **D.** Change the temperature of the materials for a better recovery; **E.** Change other parameters	# 2. Using gas or steam jet for washing #3. Modify the concentration of the detergent #4. Using high pressure for washing #5. Using carbon fiber; #6. Using smart materials for vibrations absorption #7. Using ultrasound for washing
27	3	**CHEAP SHORT-LIVING OBJECTS: A.** Replace an inexpensive object with a multiple of inexpensive objects, comprising certain qualities (such as service life, for instance);	# No ideas
13	2	**THE OTHER WAY ROUND: A.** Invert the action used to solve the problem; **B.** Make movable parts (or the external environment) fixed, and fixed parts Movable; **C.** Turn the object (or process) 'upside down'.	#8. Small dimension-portable washing machine;

Thus, eight conceptual solutions have emerged that will be used in product development.

2.2.2. Concepts generation using CREAX ideality indicators

Analyzing the current state of the development of a washing machine, notes were given for each of the CREAX [7, 8] indicators (Table 7 and figure 3). For some indicators there were proposed conceptual solutions of improvement, in the sense of evolution towards ideality (Table 8).

2.2.3. Concepts generation using technical systems evolution law

In Table 9, grades were given in accordance with the degree of satisfaction of the eight laws of the evolution [7] of technical systems for the current product. For some laws, improvements have been proposed and the new improved product was reevaluated to establish the degree of that law satisfaction.

Table 7

INCREASE IDEALITY DEGREE

Grade / Indicator	0-1	1-2	2-3	3-4	4-5	5-6	6-7	7-8	8-9	9-10			Actual Grade	New grade
1. Object segmentation	Mono-lithic solid	Segmen-ted solid	🟨 Highly segmen-ted solid	Solid granules	Solid powder	Mono-lithic liquid	Segmen-ted liquid	Aerosol	Gas	Plasma	Field	Sparse field	2	2
2. Space segmentation	**Solid**	**Hollow**	🟨 **Several hollows**	**Pores**	**Addition of active elements**								**5**	**5**
3. Surface segmentation	**Smooth surface**	**Surface with protrusions in 2D**	🟨 **Surface with protrusions in 3D**	**Rough surface with active pores**									**6**	**6**
4. Evolution of linear constructions	0 D (Point)	1 D (Line)	2 D (Plane)	🟨 3 D (volume)	Other (complex)								7	7
5. Evolution of volumetric constructions	**Plane**	**2D-curve**	**Axi-symetric**	🟨 **3D-curve**	**Fully 3D**								**7**	**7**
6. Rhythm coordination	🟨 **Continuous actions**	🟧 **Pulsating actions**	**Pulsating actions in the rezonance mod**	**Traveling wave**									2	7
7. Action coordination	**Non-coordinated action**	**Partially coordinated action**	🟨 **Coordinated action**	🟧 **Action during intervals**									7	9
8. Dynamization	**Immobile**	**Single/multiple joint**	🟨 **Completely flexible**	**Liquid/gas**	**Field**								4	
9. Human involvement	**Human**	**Human + tool**	**Human + powered tool**	**Human + semiaut. tool**	🟨 **Human + autom. tool**	🟧 **Human + fully autom. tool**							7	10
10. Controllability	**Direct control**	🟨 **Control through intermediary**	**Addition of feedback**	🟧 **addition of intelligent feedback**									4	10
11. Mono-bi-poly-Similar objects	🟨 **Mono system**	🟧 **Bi system**	**Tri system**	**Poly system**									**2**	**2**
12 Mono-bi-poly-Various objects	🟨 **Mono system**	**Bi system**	**Tri system**	**Poly system**									**2**	**2**
13. Mono-bi-poly Increasing differences	Similar components	🟨 Components with blased characteristics	Component plus negative component	Different components									4	4
14. Nature, type and dimensionality of system functions	🟨 Mono-function System	🟧 Poly-function system	Poly-function system with complementary functions	Poly-function system with opposed functions									2	4
15. System complexity	🟨 **System at max viable level of complexity**	**One part per useful function**	**One part per main useful function**										**2**	**2**
16 Number of energy conversion	🟨 **Several energy conversions**	**Reduced energy conversions**	**One energy conversion**	**No energy conversion**									**2**	**2**
17. Number of directions	**1 direction**	**2 directions**	🟨 3 directions	4 directions	5 directions								5	5
18. Number of freedom degrees	🟨 1 DOF	🟧 2 DOF	3 DOF	4 DOF	5 DOF	6 DOF							1	3
19. Smart materials	🟨 **Passive material**	**One way adaptive material**	**2 way adaptive material**	**Fully adaptive material**									**2**	**2**
20. Density, (kg/m³)	10^5	10^4	🟨 10^3	10^2	🟧 10^1	10^0	10^{-1}	10^{-2}	10^{-3}	$< 10^{-3}$			2	5
21. Macro to nano scale evolution (m)	10^2	10^1	10^0	10^{-1}	10^{-2}	10^{-3}	10^{-4}	🟨 10^{-5}	🟧 10^{-6}	10^{-7}	10^{-8}	10^{-9}	6	7
22. Webs and fibres usage degree	🟨 **Homogenous sheet**	**2D, regular mesh**	**3D, mesh with fibres aligned according to load conditions**	**Active elements**									**1**	**1**
23. Transparency	Opaque construction	🟨 Partially transparent	🟧 Transparent	Active transparent elements									4	7
24. Use of colour	No use of colour	🟨 Binary use of colour	🟧 Use of visible spectrum	Full spectrum use of colour									4	7
25. Damping	Heavy damping	🟨 Critical damping	Light damping	🟧 "Undamped"									4	9
26. Asymmetry	🟨 **Symmetrical system**	**Partial asimmetry**	🟧 **Matched asimmetry**										**2**	**6**
27. Non linearity	**Linear assumption of the system**	🟨 **Partial accommodation of system non-linearities**	**Full accommodation of system non-linearities**										**5**	**5**
28. Convolution degree C_c [0; 1]	[0; 0,1]	🟨 (0,1; 0,2]	(0,2; 0,3]	🟧 (0,3; 0,4]	(0,4; 0,5]	(05; 0,6]	(06; 0,7]	(0,7; 0,8]	(0,8; 0,9]	(0,9; 1]			1	4

🟨..... Actual Product; 🟧..... Improved product

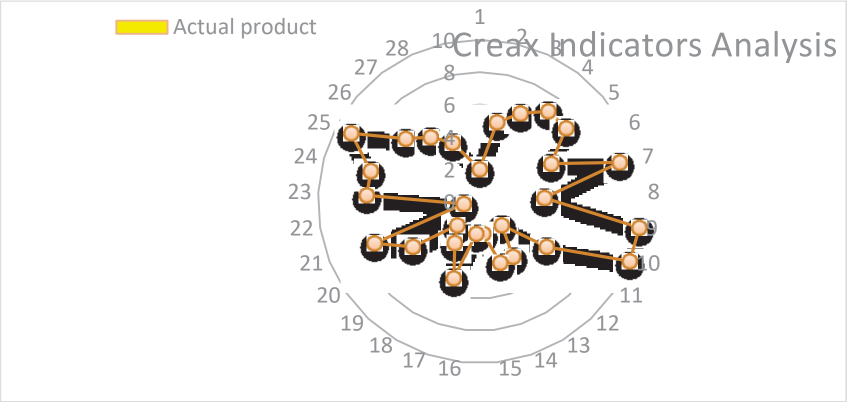


Figure 3. CREAX indicators analysis for actual and improved product

Table 8

Indicator	**Actual grade**	**Conceptual solution for improving**	**New grade**
6. Rhythm coordination	2	Pulsating action of the water; introducing ultrasonic cleaning	5
7. Action coordination	7	Actions during intervals	9
9. Human involvement	7	Increasing degree of automation	10
10. Controllability	4	Addition of intelligent feedback	10
11. Mono-bi-poly-Similar objects	2	Two drums; second drum horizontally; second device for washing using ultrasonic vibrations	5
14. Nature, type and dimensionality of system functions	2	Poly-function system: second device for washing jewellery and other household items	4
18. Number of freedom degrees	1	2 degrees of freedom for drums	3
20. Density, (kg/m^3)	2	Using materials having low density	5
21. Macro to nano scale evolution	6	Display	7
23. Transparency	4	Increasing transparency of many parts	7
24. Use of colour	4	Display	7
25. Damping	4	Reducing vibrations	9
26. Asymmetry	2	Second horizontal drum	6
28. Convolution degree $C_c \in [0; 1]$	1	Display	4

Table 9

Law	**Grade**	**Justification**	**Possible solutions**	**New grade**
Law no. 1. Law of system parts integrability: *All the technical systems must contain four parts generically named after the parts of a car: engine, gear/ transmission, control unit and work unit.*	**7**	The machine does not have a control unit to provide feedback	A system for evaluating the degree of laundry washing with program self-adjustment	**9**
Law no. 2. Law of power conductibility: *For a technical system to be viable, free energy flow must be provided inside, among its component partsn(from engine to the effector unit).*	**9**	Free energy flow	-	**9**
Law no. 3. Law of harmonisation on the pace of system parts operation: *The necessary condition of an efficient technical system operation is the coordination of action periodicity (or natural frequency) of its parts.*	**9**	Actions coordination is good	-	**9**
Law no. 4. Law of evolution towards the ideal system: *Each technical system tends towards an ideal system conceived as a system with only useful functions, with no useless or harmful functions and costs (increasing Degree of Ideality).*	**3,6**	= Mean of grades indicators from 4.4	= Mean of improved grades indicators from 4.4	**5,2**
Law no. 5. Law of unequal development of a technical system parts: *The more complex a technical system is, the more unequal its component parts development is; this development would lead to the emergence of technical and physical contradictions; system evolution will continue through solving these contradictions.*	**6**	The automation part is not evolving as development	Automating the loading of the laundry	**7**
Law no. 6. Law of system transition to super-system: *When all its development possibilities have come to an end, a technical system gets attached as an entire to a super-system, or to one of its units and all the subsequent evolution of initial system takes place in the framework of the super-system development.*	**1**	In its evolution, the washing machine did not integrate into an over-system	No ideas	**1**

Law no. 7. Law of transition from macrolevel to microlevel: *The development of system operation parts goes through macro-level evolution, subsequently passing towards micro-level. This law shows that technical systems generally evolve in the direction of fragmentation of their component parts.*	**4**	Effector unit (the drum) is not fragmented	Washing machine with two drums	**7**
Law no. 8 Law of enhanced role of the field-substance model; or the increase of dynamism and controllability: *Technical systems evolve in the direction of increased controllability and dynamism, reduced human involvement.*	**5**	= Mean of grades indicator 8 and 9 from 4.4	= Mean of improving grades indicator 8 and 9 from 4.4	**7**

2.2.4. Morphological analysis of the concepts

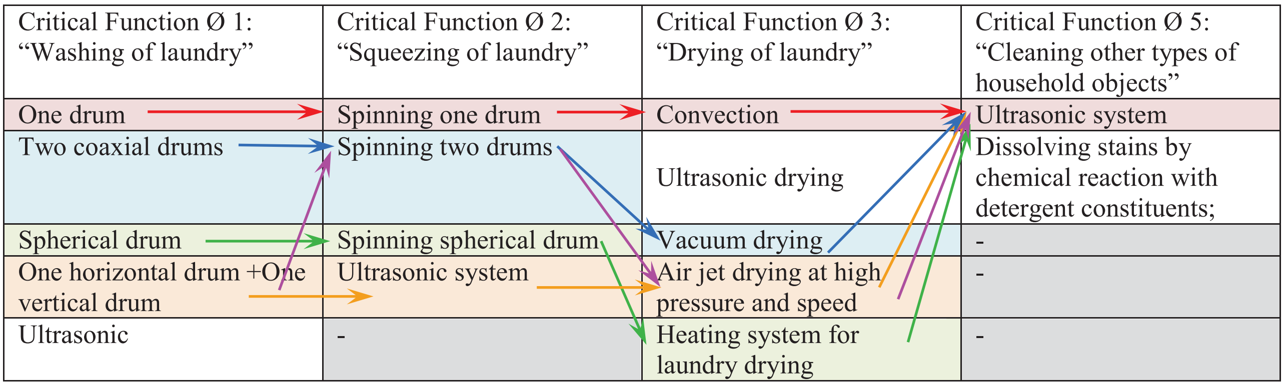
In table 10 are presented the possible partial solution for each function and for each effect.

Table 10

No. function	Critical function	Selected effects/fenomena	Possible partial solutions
1.	Washing of laundry (Ø1)	F11. Jet erosion; F12. Redox reactions; F1.3. Ultrasonic oscillations, cavitation, acoustic cavitation, acoustic vibrations; F1.4. Friction; F1.5. Dissolutions; F1.6. Electrochemical erosion; F1.7. Hydrodynamic; F1.8. Thermo-destruction; F1.9. Mechanical action; F1.10. Adsorption (reverse).	S1a. Dissolving stains by chemical reaction with detergent constituents; S1b. Ultrasonic Cavitation Washing; S1c. Normal friction washing S1d. Multi-directional rotation (sphere drum); S1e. Hydrodynamic pulses (two drums).
2.	Squeezing of laundry (Ø2)	F2.1. Absorption (reverse); F2.2. Centrifugal separation; F2.3. Electro-osmosis; F2.4. Ultrasound; F2.5. Heating.	S2a. Centrifugation/Spinning (variable drum speed); S2b. Use of ultrasonic vibrations
3.	Drying of laundry (Ø3)	F3.1. Acoustic vibrations; F3.2. Centrifuge; F3.3. Convection; F3.4. Ultrasonic drying; F3.5. Vacuum drying; F3.6. Air impingement.	S3a. Convection; S3b. Ultrasonic drying; S3c. Vacuum drying; S3d. Air jet drying at high pressure and speed. S3e. Heating system for laundry drying
4.	Cleaning other types of household objects (Ø5)	**F5.1.** Jet erosion; F5.2. Redox reactions; **F5.3.** Ultrasonic oscillations, cavitation, acoustic cavitation, acoustic vibrations; **F5.4.** Friction; **F5.5.** Dissolutions; **F5.6.** Electrochemical erosion; **F5.7.** Hydrodynamic; F5.8. Thermo-destruction; F5.9. Mechanical action; F5.10. Adsorption (reverse).	S5a. Cleaning using ultrasonic system S5b. Dissolving stains by chemical reaction with detergent constituents;

Of all the above solutions, a few were retained for each critical function and were ordered in Table 11 to generate concepts.

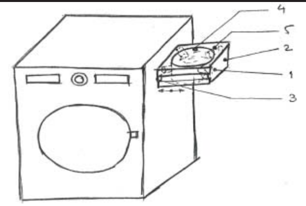
Table 11

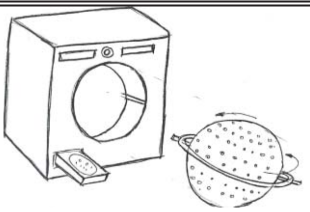
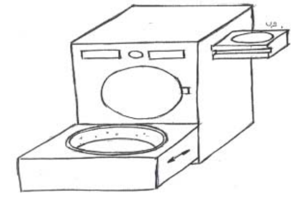


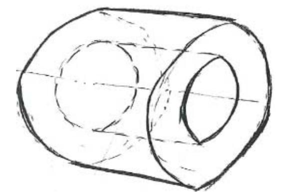
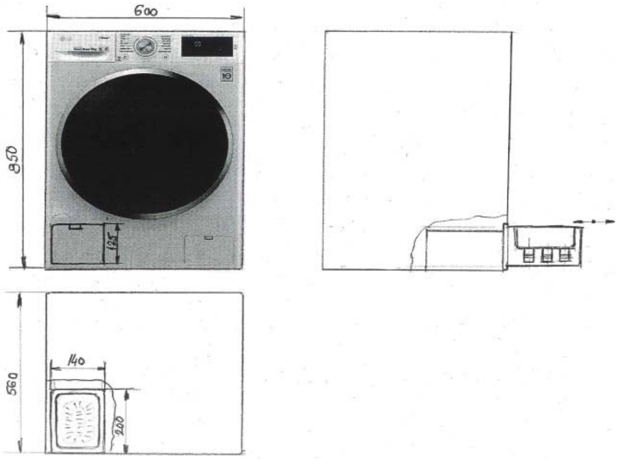
Critical Function Ø 1: “Washing of laundry”	Critical Function Ø 2: “Squeezing of laundry”	Critical Function Ø 3: “Drying of laundry”	Critical Function Ø 5: “Cleaning other types of household objects”
One drum	Spinning one drum	Convection	Ultrasonic system
Two coaxial drums	Spinning two drums	Ultrasonic drying	Dissolving stains by chemical reaction with detergent constituents;
Spherical drum	Spinning spherical drum	Vacuum drying	-
One horizontal drum +One vertical drum	Ultrasonic system	Air jet drying at high pressure and speed	-
Ultrasonic	-	Heating system for laundry drying	-

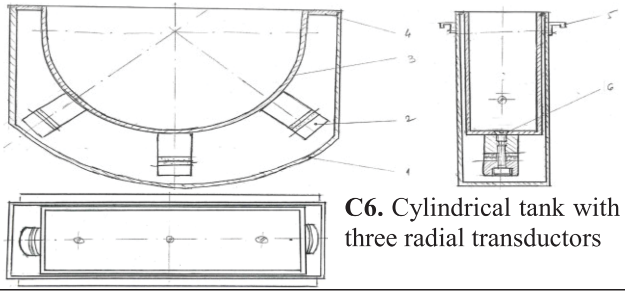
Maximum number of combinations = k_1 x k_2 x …. x k_n = 5 x 4 x 5 x 2 = 200. After the concepts were sorted, the concepts presented in Table 12 were selected. Using the Analytic Hierarchy Process method the optimal concept C5+C7 was established.

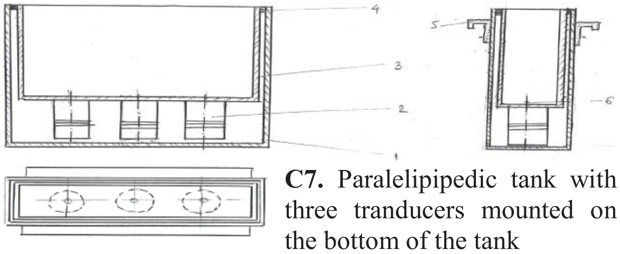
Table 12. Concepts

<table>
<tr>
<td>

C1. Washing and squeezing the laundry using one cylindrical drum, drying by convection and lateral retractable ultrasonic system for cleaning of other types of household objects.</td>
<td>
C2. Washing and squeezing the laundry using one spherical drum, drying by heating and front retractable ultrasonic system for cleaning of other types of household objects.</td>
<td>

C3. Washing and squeezing the laundry using one horizontal drum +one vertical drum, drying by air jet at high pressure and speed and lateral retractable ultrasonic system for cleaning of other types of household objects.</td>
<td>
C4. Washing and squeezing the laundry using two coaxial drums, drying by vacuum and lateral retractable ultrasonic system for cleaning of other types of household objects.</td>
</tr>
<tr>
<td colspan="2" rowspan="2">

C5. Washing and squeezing the laundry using one cylindrical drum, drying by convection and front retractable ultrasonic system for cleaning of other types of household objects.</td>
<td colspan="2">

C6. Cylindrical tank with three radial transductors</td>
</tr>
<tr>
<td colspan="2">

C7. Paralelipipedic tank with three tranducers mounted on the bottom of the tank</td>
</tr>
</table>

3. Conclusions

Based on the research presented in this paper we can formulate several conclusions:

1. The paper aims to develop a washing machine that incorporates an ultrasonic washing system for small household items;

2. Using functional analysis and various methods of generating concepts, various conceptual solutions were generated and an optimal concept was established;

3. Research will continue with the detailed design of the product;

4. Bibliography

[1] Brilhante SJ, Freitas J., et. al., Benicio J., *Decontamination by ultrasound application in fresh fruits and vegetables,* FOOD CONTROL, Volume: 45, Pages: 36-50, Nov 2014

[2] Hesson JR, Fundamentals of ultrasonic cleaning, www.hessonic.com, accessed December, 15, 2019

[3] Ionescu C., Chiru R., Popescu L.N., *Creativity and Intellectual Property – Project*, UPB, 2018

[4] Ionescu C., Chiru R., Popescu L.N., *Research Regarding Ultrasonic Washing, Scientific Rep 1*, UPB, Jan. 2019

[5] Ionescu C., Chiru R., Popescu L.N., *Research on Ultrasonic Cleaning with Applications in Development of Home Appliances,* Sesiunea ştiinţifică studenţească, UPB, Mai, 2019

[6] Ionescu C., Popescu L.N., Chiru R., *Research on Ultrasonic Cleaning with Applications in Development of Home Appliances, Scientific Report 3*, UPB, January 2020

[7] Ionescu N., Vişan A., Stoicescu D., *Creativity and intellectual Property*, Editura BREN (Cod CNCSIS 96), Bucureşti, 2016, ISBN 978-606-610-188-2.

[8] ***, *The CREAX Innovation Suite 3.1*, user manual and software, accessed April, 15, 2019

[9] ***, www.aulive.com, accessed, November 8, 2018