RESEARCH REGARDING DEVELOPMENT OF A WASHING MACHINE INCLUDING SPECIAL DEVICE FOR SMALL OBJECT CLEANING

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ABSTRACT:
The paper continues previous research by the authors by developing parts of conceptual design and detail design. As a novelty, the constructive solution is introduced based on the introduction of the ultrasonic cleaning system in the door of the washing machine. It presents the concepts resulting from the application of a large number of methods for generating concepts as well as optimally conceptual stability through the application of the AHP method. Regarding the detailed design, both the realization of the prototype through additive manufacturing and the design of the series product are approached.

KEY WORDS: Ultrasonic cleaning, household objects, washing machine

1. Introduction

Ultrasonic vibrations have important industrial applications [1, 2], especially for active applications (the dimensional processing of materials, ultrasonic cleaning/degreasing, ultrasonic activation of both physicochemical processes and conventional processing methods) and passive applications (ultrasonic defectoscopy - non-destructive control of different parts, measurement of physical quantities, measuring geometric dimensions).

Although the application in the home field is still in its infancy, some successful products on the market can be noticed, such as [1, 2, 4]: ultrasonic system for washing small household objects or fruits and vegetables, ultrasonic washing machines, ultrasonic pen for cleaning clothes on clothes, portable ultrasound device for laundry washing, other ultrasonic washing systems.

In previous works [3, 4, 5, 6], the authors made detailed studies on the application of ultrasound, constructive solutions for the realization of ultra-acoustic systems, sizing of ultra-acoustic systems. The research was focused on making a washing machine with a built-in ultrasonic cleaning system for small household items such as watches, jewelry, glasses, manicure and pedicure kits, etc. Based on the analysis of customer needs and requirements and on the systemic analysis of the product, a market study was conducted [6, 7] which established the target specifications of the product. The functions of the new product have been established [6, 7] taking into account specific functions of the ultrasonic cleaning system. For the generation of concepts (conceptual design) a large number of methods were applied (QFD, TRIZ, 9 screen method, classical ideality indicators, CREAX ideality indicators, physical contradiction, Su-Field analysis, CREAX software, technical systems evolution law).

In the present paper, the authors introduced two new concepts regarding the inclusion of the ultrasonic system inside the door of the washing machine. The conceptual design was partially redone, the optimal concept was selected and the detailed design was started. The research will continue with the completion of the detailed design, the establishment of the manufacturing technology of some component parts, the intellectual property rights and the economic analysis.

2. Conceptual design of device for small object cleaning

For the conceptual design, the concepts presented by the authors in previous works [6, 7] were supplemented. Thus, for the critical function Ø 5 "Cleaning other types of household objects" two new solutions were introduced:

- Ultrasonic system inside the front door (new conceptual solution);
- Ultrasonic system inside the case of the washing machine at the bottom left (improved conceptual solution).

Based on a study made with the help of databases [8, 9, 10] was initially selected a wider range of phenomena that underlie the realization of functions Ø1 - Washing and Ø5 – Cleaning: Jet erosion; Redox reactions; Ultrasonic oscillations, cavitation, acoustic cavitation, acoustic vibrations; Friction; Dissolutions; Electrochemical erosion; Hydrodynamic; Thermo-destruction; Mechanical action; Adsorption (reverse).

Based on the study of the phenomena underlying each function, the morphological analysis was redone according to those presented in table 1 to generate the concepts.

Table 1

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 inside the front door
Two coaxial drums	Spinning two drums	Ultrasonic drying	Dissolving stains by chemical reaction with detergent constituents;
Spherical drum	Spinning spherical drum	Vacuum drying	Ultrasonic system inside the case of the washing machine at the bottom left
One horizontal drum +One vertical drum	Ultrasonic system	Air jet drying at high pressure and speed	Ultrasonic system inside the case of the washing machine – lateral right
Ultrasonic	-	Heating system for laundry drying	-

Maximum number of combinations = $k_{ø1} \times k_{ø2} \times \ldots \times k_{øn} = 5 \times 4 \times 5 \times 4 = 400$, where k is the number of the solutions for each function. After the concepts were sorted, the concepts presented in Table 2 were selected. Using Analytic Hierarchy Process (remade in the new context) the C4 and C5 concepts came out on the first two places with very close scores.

Table 2. Concepts

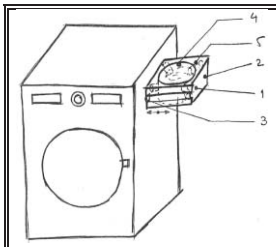
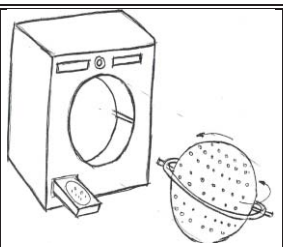
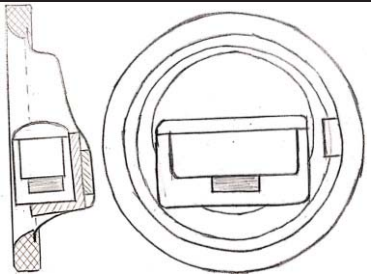
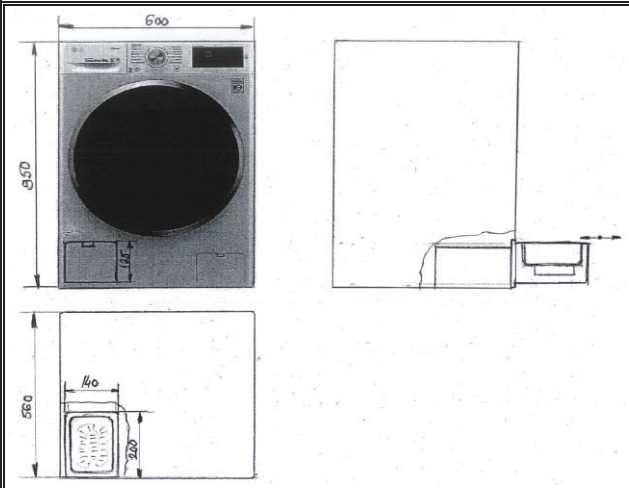
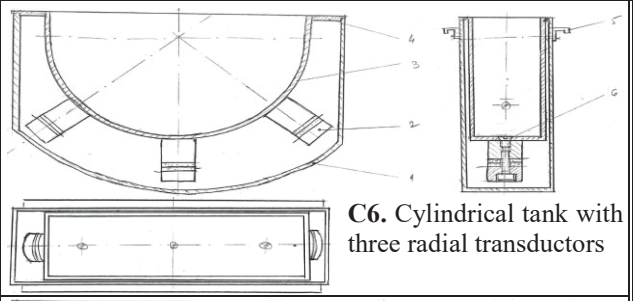
 **C1.** Washing and squeezing the laundry using one cylindrical drum, drying by convection and lateral retractable ultrasonic system for cleaning of other types of household objects.	 **C2.** Washing and squeezing the laundry using one spherical drum, drying by heating and front retractable ultrasonic system for cleaning of other types of objects.	 **C3.** Washing and squeezing the laundry using one horizontal +one vertical drum, drying by high pressure and speed air jet and lateral retractable ultrasonic system for cleaning of other types of objects.	 **C4.** Washing and squeezing the laundry using one cylindrical drum, drying by convection and ultrasonic system inside the front door for cleaning of other types of household objects.

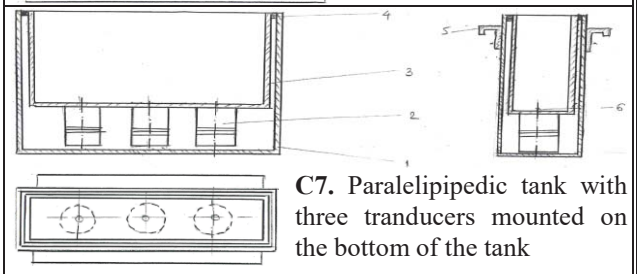
Table 2. Concepts (continuation)



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.



C6. Cylindrical tank with three radial transductors

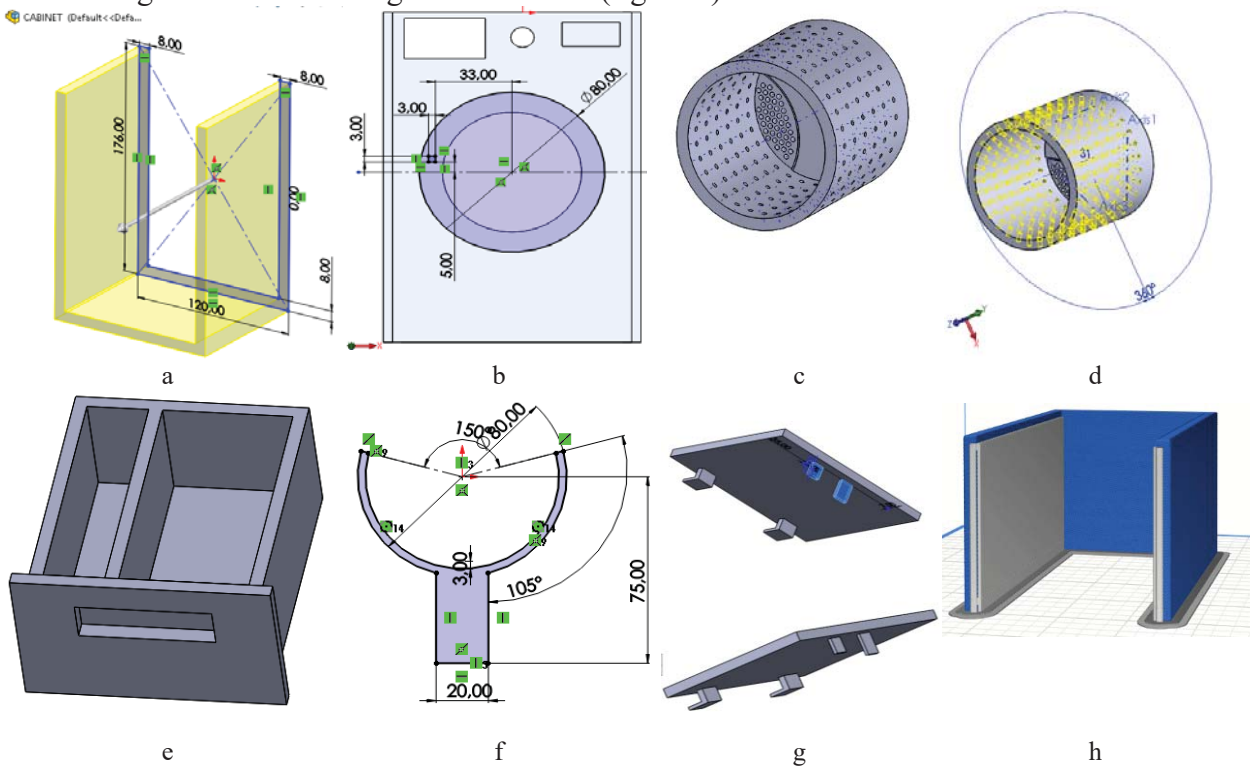


C7. Paralelipipedic tank with three tranducers mounted on the bottom of the tank

3. Detail design of device for small object cleaning

3.1. Prototype design and realization

For CAD Design of the washing machine, the main components were established as follows: cabinet, front panel, back cover, drum, drum cover, front door, detergent drawer, knob, upper cover. The CAD Design started with the main body, thus the cabinet. The main profile was drawn using measurements according to the possibilities for printing (i.e. 900x900). Therefore, the washing machine was designed a 5:1 scale (figure 1).



a b c d

e f g h

Figure 1. Parts' design

The Front Panel was designed taking into account the measurements of the cabinet, and most of all, the measurements of the channel for sliding the front panel (figure 1b). Therefore, a new sketch was created for designing the entrance of the detergent drawer using *Cut-Extrude*. In the same way as mentioned before, it was designed the knob entrance. Afterwards, it was designed the Display Area by creating a new sketch and using *Cut-Extrude* as it can be observed in the following pictures.

The design of the drum for the washing machine is presented in Figure 1c, according to the dimensions of the front panel. For this, a circle of Ø80 was created, followed by extrusion by 70mm using *Boss-Extrude*. The left side was designed for the detergent and softener, and the right side was designed larger, for the ultrasonic system as shown in the Figure 1e.

The next component designed for the washing machine was the program selector, named in the Bill of Material of the prototype as *Knob.* For this, the front panel was measured for choosing the adequate values. A new sketch was created and a Ø9 circle was drawn. The next step shows a support that will hold the drum cover. For this it was constructed a profile according to the dimensions of the drum (Figure 1f).

In order to close the washing machine, an upper cover was designed meaning 3D model of blockers for the *Knob* and *Detergent Drawer*. The main profile together with its extruding can be observed in Figure 1g, where the dimensions were chosen according to the dimensions of the U profile. The last component of the washing machine was the *Front Door.*

a b c d

e f

Figure 2. The 3D printed components of the washing machine

After designing the prototype, the assembly was printed using Sigmax and Zortrax Printers, through Cura and Z-Suite Software in the Additive Manufacturing Laboratory of Industrial Engineering and Robotics Faculty from POLITEHNICA University of Bucharest. The first body printed was the U profile, which was saved from SolidWorks as STL format accepted by Z-Suite application (figure 2a). Afterwards, the printing parameters were set together with support printing in the second one. The next 3D model printed was the Front Panel (Figure 2b). For this application, it was used Cura Ultimate Printing Software. The design part was saved as a .STL format, introduced and placed together with setting the properties. Afterwards, it was sent to the Sigmax Printers, the steps being described by the side picture. The total printing time for the part was 5 hours and 7 minutes. In similar ways, through similar procedures were printed the other parts of the washing machine (figure 2 c, d) using the same software and printers, and the same materials (i.e. Light Blue PLA). Moreover, it was kept the same Profile, thus Standard Quality – 0.25mm, and same printing temperature for the Initial Layer, 220ºC. Where necessary, it was added support for printing. The software allows to easily position the desired parts to be printed. In these pictures, the application renders the product and gives a preview showing the layers applied during the printing program.

Finally, the product was assembled (figure 2 e, f). The assembly was inserted in SolidWorks where it was taken the U-profile and make it a fix item. Therefore, it was added the back cover by applying *Mates* (Figure 2 e, f).

We can conclude that the project meets the requirements regarding its main functionality, thus the implementation of an ultrasonic system. This system includes the possibility of washing other objects than clothes, like jewelry, pedicure sets, etc. The designing stage was achieved at a proposed level, as the washing machine prototype was drawn and designed with most of washing machine parts. Several improvements can be performed on the construction of the prototype. These could be: changing the way the drum is place and sustained, trying to find other possibilities with others design; it needs to be found a system that will allow the door to open fully, with a similar system as the one of a hinge with bolts.

3.2. Detailed design of series product

Each of the two concepts selected in subchapter 3.2 were developed in two variants, as follows:

- Detail 5.1. Mounting of ultrasonic system inside the case of the washing machine at the bottom left with original housing and adapter elements;
- Detail 5.2. Mounting of ultrasonic system inside the case of the washing machine at the bottom left without original housing and with adapter elements;
- Detail 4.1. Mounting of ultrasonic system inside the front door with original housing and adapters;
- Detail 4.2. Mounting of ultrasonic system inside the front door without original housing and with adapter elements.

For the beginning, it was designed the concept 4, which consists in inserting the ultrasonic system inside the front door of the washing machine. We started from the initial design of the front door of the washing machine, represented in figure 3 and 4. The project envisages the development of a solution to be included as an extra-option when purchasing a washing machine, for which the customer is willing to pay extra.

In modeling the casing of the ultrasonic system, it was taken into account that the window of the front door of the washing machine has a complex shape (figure 5).

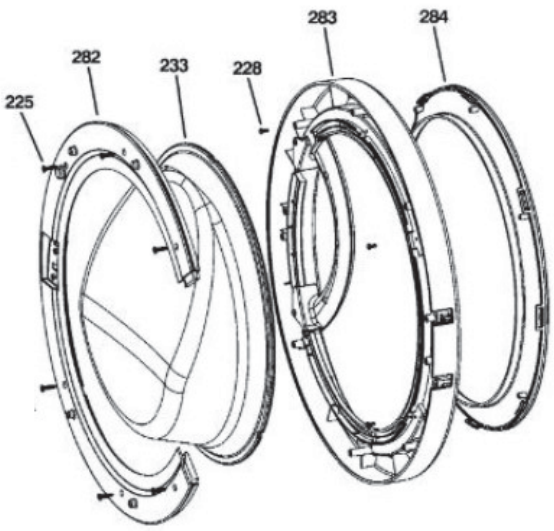


Figure 3. Initial draw of the front door [11]

Figure 4. view of the front door

After designing the front door, the housing of the ultrasonic system was designed, as well as the solutions for attaching it to the door of the washing machine (figure 5), so that it can withstand the total mass of the ultrasonic equipment (0.75 kg) and withstand the vibrations that occur in laundry time.

In the designed version and in figure 5 is not represented the spherical cap that covers the outer part of the door available to some models of washing machines.

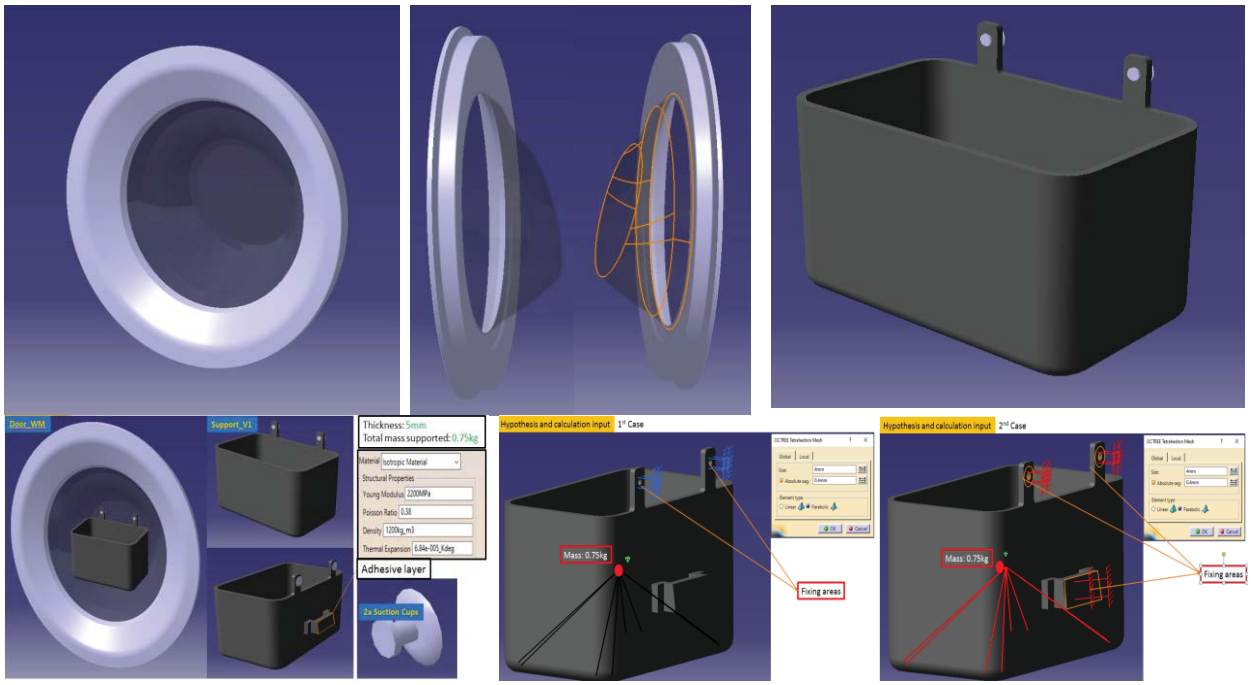


Figure 5. Door and ultrasonic system design

In order to minimize the costs of the manufacturing process, a modal analysis will be performed to establish an optimal design for series production. For this, the finite element (mesh) was defined and the 3D model was discretized.

For the modal calculation, the connection between the contact surfaces, respectively the hole surfaces and the required point between the support and the washing machine window was made. For this case, the modal frequency test is performed under the weight of the system fixed inside the 3D support (ultrasonic system 750g). The modeling will continue by performing the tests in own mass (figure 6).

Similarly, in the second case (figure 7), the same principle of modal analysis is followed, taking into account a new fixing surface. This surface has the role of gluing but also of correct positioning of the support inside the door to avoid its inclination when mounting / in load.

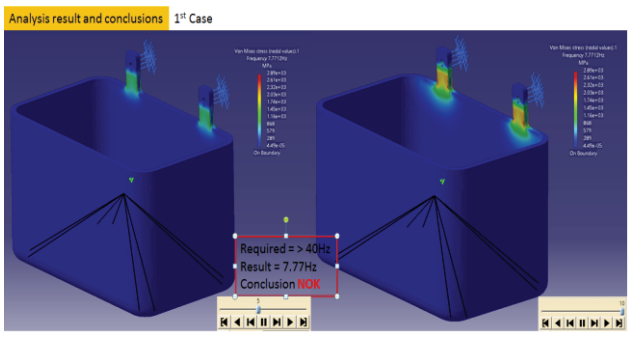


Figure 6. Test - case #1

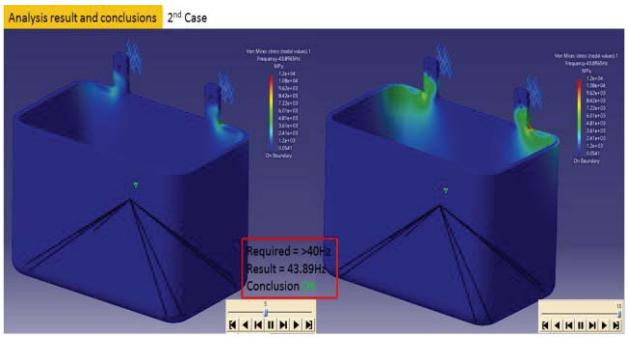


Figure 7. Test - case #2

During the analysis, several frequencies of the vibrations of the washing machine during operation can be simulated. Based on the preliminary simulations performed (figures 6 and 7), the following conclusions can be drawn:

- A value of 43 Hz > 40Hz on the washing machine housing will be feasible, it will not affect the support;

- A result of 7.77Hz <40Hz not feasible; we will resize the product (considering material / process cost) because the possibility of breaking the clamping supports;

Figure 8. Approximate image of the prototype

Figure 8 shows an image of the approximate way the washing machine door will look, made with items purchased from suppliers.

4. Conclusions

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

1. The paper continues some previous research of the authors whose ultimate goal is to design and build a washing machine that includes an ultrasonic system for washing small household items (jewelry, glasses, manicure kits, watches, etc.);

2. For the conceptual design, the concepts presented by the authors in previous works were supplemented and two new solutions were introduced: ultrasonic system inside the front door (new conceptual solution) and ultrasonic system inside the case of the washing machine at the bottom left (improved conceptual solution);

3. Based on the study of the phenomena underlying each function a wider range of phenomena that underlie the realization of functions was selected and the morphological analysis was redone in order to generate the concepts;

5. Using the AHP – Analytic Hierarchy Process method, two concepts with very close scores were established;

6. The detailed design of the conceptual variant in which the ultrasonic system is inserted in the door of the washing machine was made;

7. The work will continue by finalizing this constructive solution, by developing the concept in which the system is included in a drawer in the lower left part of the washing machine and by making the prototype variant that includes the ultrasonic system in the front door.

5. Bibliography

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