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Ultrasonic system for continuous washing of textiles in liquid layers: semi-industrial development

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Abstract: Cleaning of solid rigid materials is one of the best known power ultrasonic applications. Nevertheless, the use of ultrasonic energy for washing textiles has been tried several times without achieving practical development. In fact, the flexibility of the fibres makes the cavitation to produce small erosion effect and the reticulate structure of the fabric favours the formation of air bubble layers which obstruct wave penetration. During several years an investigation about the use of ultrasonic technologies for cleaning textiles in domestic washing machines was carried out. It was found out that by diminishing the amount of dissolved air in the wash liquor the application of ultrasonic energy improved wash results in comparison to conventional methods. Nevertheless, practical requirements hindered the commercial development of the ultrasonic washing system. Specifically, the requirements of high water level and small wash load needed to ensure efficiency and homogeneity in the wash performance. To overcome these problems for industrial applications, a new process was developed in which textiles are exposed to the ultrasonic field in a flat format and within a thin layer of liquid. Such process has been implemented at laboratory and at semi-industrial stage. The textile items are transported in a continuous way passing them underneath the radiators of specially designed power ultrasonic transducers. A series of devices select and adjust different parameters of the process. This paper deals with the structure and performance of the system

Key words: Power ultrasound, ultrasonic washing

A. Introduction

Cleaning of solid rigid materials is one of the best known applications of power ultrasound. As well known, the cleaning action of ultrasonic energy is mainly due to cavitation and related phenomena. Nevertheless the use of ultrasonic energy for washing textiles has been tried over several years without achieving practical development. The strategies for ultrasonic washing have been generally directed towards the production of cavitation in the entire volume of liquid in which the fabrics to be washed are placed. Such systems have significant inconveniences. In fact, it is practically impossible to achieve a homogeneous distribution of the acoustic field in the entire washing volume. Then in the areas of low acoustic energy the cavitation threshold is not reached and it causes the washing to be irregular. To overcome the situation the washing time must be increased and the washing treatment must be done with a low proportion of fabric per volume of liquid. In addition, the fabric must be moved so that it passes through the areas of high energy of the washing cavity. Other general difficulties come from the flexibility of the fabric which make the cavitation to produce small erosion effect as well as from the reticulate structure of the material which favours the formation of layers of big bubbles that obstruct wave penetration.

During several years we have been investigating about the use of ultrasonic technologies for cleaning textiles in domestic washing machines. It was found out that by diminishing the amount of dissolved air in the wash liquor the application of ultrasonic energy improved wash results in comparison to conventional methods [1]. Nevertheless, practical requirements have hindered the commercial development of the ultrasonic washing system. Specifically, the requirements of high water level and small wash load needed to assure efficiency and homogeneity in the wash performance. To overcome these problems for industrial applications a new process was developed in which the textiles are exposed to the ultrasonic field in flat format and within a thin layer of liquid. Such process was been implemented at laboratory and semi-industrial stage. This paper deals with the structure and performance of the developed system.

B. Description of the procedure

The new washing procedure is based on the application of the ultrasonic energy to the textiles to be washed by means of special vibrating plate radiators that are in direct contact or very close to them. The textiles are submerged in a shallow layer of liquid and conveyed in a flat format through the ultrasonic radiator by means of a roller-type system (Fig. 1). The plate radiator is designed to vibrate with one of its simpler flexural vibration modes to avoid as much as possible great differences in the vibration amplitudes.

The cleaning effect is produced by the intense cavitation field generated by the plate radiator in the thin layer of liquid. Such liquid layer is very favourable to produce high cavitation effect [2] and is very convenient for the low consumption of washing liquor required. The homogeneity in the washing effect is achieved by moving the fabrics along the plate surface in such a way that all parts part of them are exposed during the same time to the areas of intense acoustic field.

The high intensity radiation directed over the surface of the textiles helps to remove the big bubbles by the action of the radiation force and the requirement of degassing the liquid is not necessary in this process.

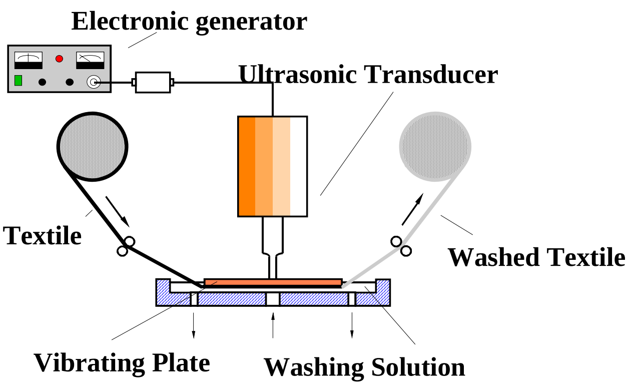

Fig. 1. Basic scheme of the process

C. Experimental laboratory set-up

The washing procedure [3] previously described was initially implemented at laboratory stage by means of the set-up shown in Fig. 2. It basically consists of a rectangular plate power ultrasonic transducer located in a container with a conveyor roller system.

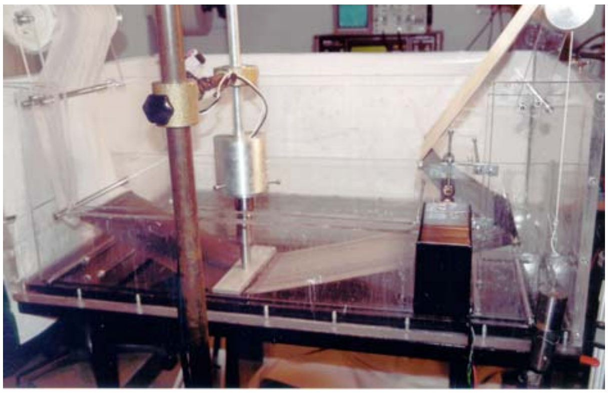

Fig. 2. Laboratory set-up

The transducer used in the laboratory set-up consisted of a rectangular aluminium plate of about 22 cm in length and 1 cm in thickness driven by a piezoelectric vibrator. The plate radiator was designed to operate at about 20 kHz with a flexural mode of two nodal lines parallel to the longer side of the plate. This transducer has a maximum power capacity of about 200W. Therefore the applied intensity was of about 1.5 W/cm^2. By using this set-up the influence of the ultrasonic energy on the washing performance was studied for a number of representative stains present on different kind of standard test pieces: EMPA 101 (cotton soiled with carbon black and olive oil) AS9 (polyester/cotton soiled with fatty material and solid particles) and WFK30D (polyester soiled with skin fat and pigments). Figure 3 shows the cleaning results obtained by using the ultrasonic system compared with those achieved with a conventional washing machine.

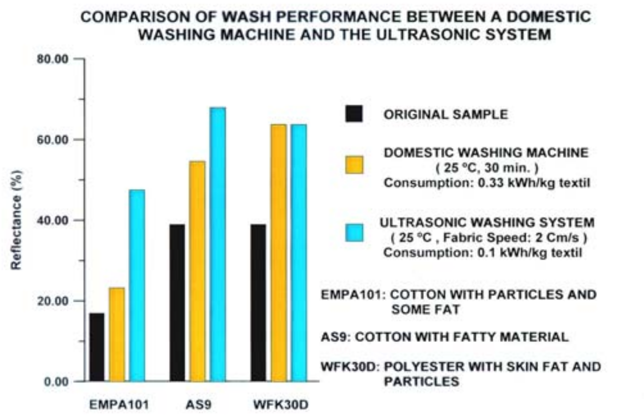

Fig. 3. *Comparison of wash performance*

D. Semi-industrial unit

As a consequence of the good results obtained at laboratory stage, an improved washing system has been developed for semi-industrial purposes. The basic objectives for this system are: to improve the performance of the plate transducer for industrial operation, to increase the number of transducers in order to increase the washing speed and to control and optimize the parameters of the process (liquid layer thickness, transducer-fabric distance,...)

The plate transducer constitutes the main part of the system. To work under industrial conditions requires a high power capacity to safely produce strong cavitation in the washing liquid.

The main drawback of the transducer designed and constructed for the laboratory set-up was the high-density of vibration modes of the plate radiator in the range of the operating frequency. This fact is particularly important at high excitation levels in liquids when the driving signal may suffer distortion and the band becomes wider. In this case, the vibration modes easily interact causing serious disturbances in the process and even damages in the transducer.

To avoid this problem the design of the plate radiator was modified by using finite element methods and following a procedure we developed to control the vibration mode of stepped plate radiators. This procedure basically consists of designing the plate radiator with a grooved profile on its back side. Such profile is obtained by uniformly removing mass from all the central area of the plate between the two nodal lines (fig. 4). In this way the response of the operating mode is favoured by diminishing its impedance while the other modes are obstructed. In fact, in the flat plate radiator appear six modes in the range 19-21 kHz, while in the grooved plate radiator only appear the operating mode (21 kHz) in the range 20-22 kHz.

The new grooved-plate radiator has been constructed in titanium alloy. The resulting transducer has a power capacity of about 600W with a radiating surface of about 110 cm^2. It means a capability for reaching acoustic intensities around 5W/cm^2. The main characteristics of such transducer measured in air and in water are:

Table 1: Characteristics of the grooved-plate transducer at low power

	Frequency	Bandwidth	Impedance
In air	21930 Hz	13.5 Hz	18Ω
In water	21070 Hz	61 Hz	135Ω

Two of such transducers are installed in the semi-industrial washing unit shown in Figure 5. Such unit consists of a container constituted by a soaking bath to wet the fabric and the washing volume. The unit is provided of several rollers to convey the fabric in a flat format parallel to the radiator surface. The fabric is moved in a perpendicular direction to the nodal lines of the flat radiator. A motor is moving the whole system. The distance between the radiators and the fabric as well as between the radiators and the bottom of the container, which act as a reflector, may be adjusted by high-precision mechanical devices. Each transducer is driven by an electronic system which basically consists of an electronic controller to generate and control the driving signal, a power amplifier and a matching impedance circuit (Fig.6).

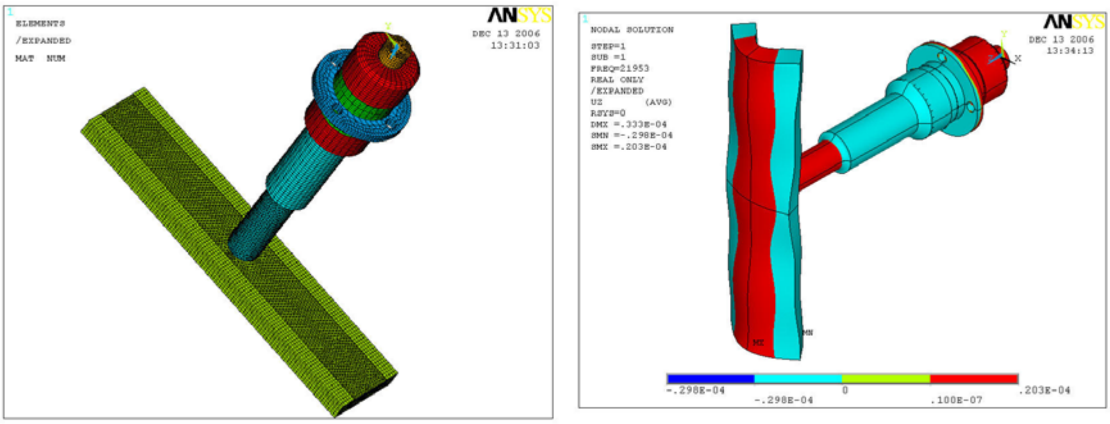

Fig. 4: FEM schemes of the grooved plate transducer and of the vibration phase distribution

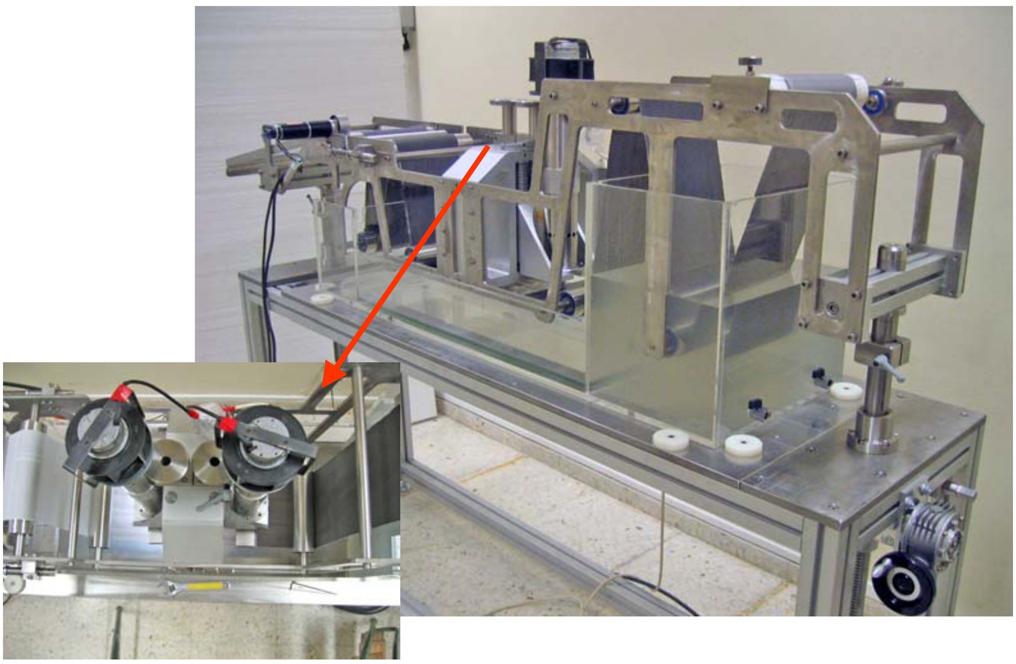

Fig. 5. Photographs of the semi-industrial unit and a detail of the washing volume

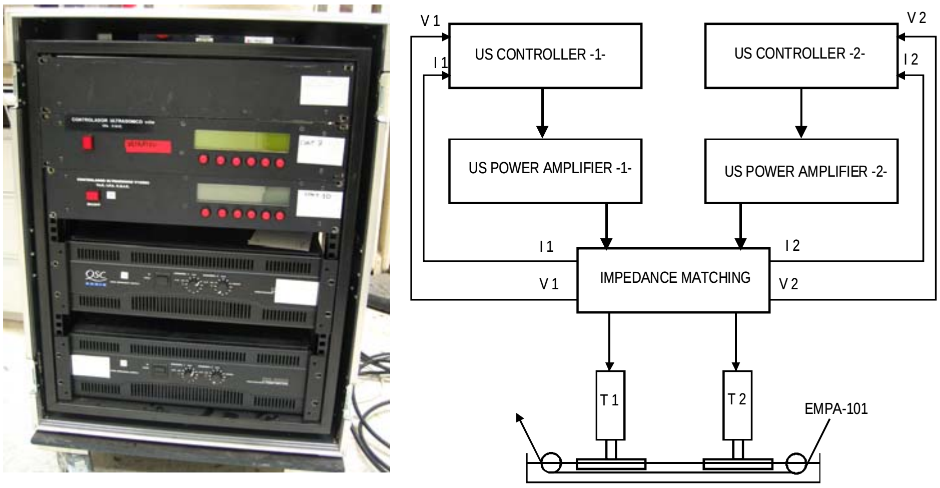

Figure 6: Scheme and Photograph of the electronic equipment

The distance between the transducers and the reflector was optimized electrically, by measuring the transducer admittance at different distances and mechanically by measuring the cavitation activity on aluminium foils placed on the container bottom. The selected value was of about 17mm. The distance between the transducer and the fabric was of about 1mm.

The washing tests done under these conditions confirm the good washing results previously obtained at laboratory stage. However, further tests have to be done in order to exhaustively quantify all the parameters needed to scale up the system at industrial level.

E. Conclusions

A semi-industrial ultrasonic system for the continuous washing of textiles in liquid layers, based on a procedure previously studied, has been designed and constructed. The system incorporate as the main part new plate transducers in which the interaction of different vibration modes produced under high-power operation have been avoided. Such transducers have shown good and safe performance at high power continuous operation and, therefore, represent an adequate solution for industrial application.

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The developed system has confirmed the good washing results obtained at laboratory stage and is prepared to quantify all the parameters needed to scale it up for industrial applications.

F. Acknowledgments

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