

VIBRATION MODES FEM ANALYSIS OF THE ULTRASONIC TRANSDUCER USED TO REDUCE THE FRICTION FORCE DURING WIRE DRAWING

Anda Nicoleta Cringureanu[1], Marilena Gheorghe[1*], Popescu Alexandra*[1], Andreea Otomega[1], Oana Chivu[1], Dan Nitoi[1]
[1] National University of Science of Technology Politehnica Bucharest

ABSTRACT: The article presents the determination and study of the natural vibration frequencies of an ultrasonic system that will be used in the "ultrasonic lubrication" necessary to reduce the coefficient of friction when drawing wires. Obtaining wires through wire drawing has been and will develop more and more strongly as an absolutely necessary industry, especially in the context of the transition to green energy involving photovoltaic panels and wind power plants. Along with their development, there is an absolutely imperative need to transport electricity from the place of its production to the points of its transformation or use. In this sense, the distances to be covered are of the order of hundreds of Km or even more. The companies in this industry, and here we can note the company Prysmian from Slatina, have already signed contracts for the next five years for the production of aluminum or copper cables. The research in this field comes to offer a solution to the reduction of the forces necessary for wire drawing by installing such ultrasonic systems within the wire drawing machines.
KEYWORDS: ultrasonic, friction, reduction, wire, drawing

1. INTRODUCTION

Modeling and simulation have been an extremely valuable research tool for many decades, proving their effectiveness in many scientific fields, from the consumer goods industry to the most advanced industries such as the automotive industry, medicine, the nuclear industry, the aerospace industry, and astronomy. These leading industries benefit from M&S opportunities because they provide answers to particularly complicated questions that cannot be obtained through experiments. It is worth noting that the most complex mathematical models preceded experimental results by many years or decades. Some notable examples can be found in the prediction and modeling of black holes in the cosmos, the Higgs boson, and gravitational waves, which were first predicted and mathematically thought out so that experiments could validate these models. Mathematical models provide answers about the formation of the cosmos, the universe, and the prediction of thermal fields in remote and very remote areas where there is no method for evaluating them. Mathematical models are generally grouped into two broad categories, namely analytical models and models based on the use of the finite element analysis method. Although the Finite Element Method (FEA) is based on the same analytical differential equations that underlie engineering and science in general, the way this method works and its implementation are different and offer computational speed for complex and very complex structures.

Returning to the engineering fields, on the other hand, modeling and simulation offer particularly useful and interesting results in optimizing structures from both a mechanical and thermal point of view.

Realizing the full potential of M&S will require a revolution in simulation technology. Simulation-based technology is not “simulation as usual”; rather, research is focused on modeling and simulating complex, interdependent engineering systems and obtaining results that meet precise standards of accuracy and reliability. Indeed, the scope of M&S includes much more than modeling physical phenomena. It develops new methods, devices, procedures, processes, and planning strategies. It not only builds on and stimulates advances in scientific understanding but also capitalizes on these advances by applying them to engineering challenges. For example, discoveries in M&S have direct applications in optimization, control, uncertainty quantification, verification and validation, decision making, and real-time response. In short, M&S will take this working technique to a new, powerful level, a level where it is hoped to solve the most difficult problems of modeling, engineering design, manufacturing and scientific research.

2. WIRE DRAWING PROCESS

Wire drawing is the main process in the manufacturing of power cables. Figure 1.1 shows the layout of the utilities within a drawing section where electric cables are obtained. Drawing and drawing are technological processes for obtaining semi-finished products through plastic deformation, in which the metal material under the action of a drawing force is forced to pass through a calibrated hole of a tool, which is smaller than the initial section of the material. The tools for wire drawing are called dies, and for drawing - dies. Drawing is the technological process of obtaining a wire of smaller dimensions (diameter f), by cold deformation of a ductile product (diameter F), through successive passes through a series of dies.

If the traction force is provided by a drum, drum or roller, on which the deformed material is wrapped, the process is called drawing; if the traction force is exerted by a machine body with rectilinear movement, and the deformed products (bars or pipes) are obtained straight, the technological process is called pulling.

During wire drawing, the state of tension is a complex one and consists of a compressive stress to which is added a tensile stress, which deforms the crystalline structure, through sliding and elongation, which allow the preservation of the cohesion of the structure of the material to be processed. The drawing principle diagram is presented in figure 1.

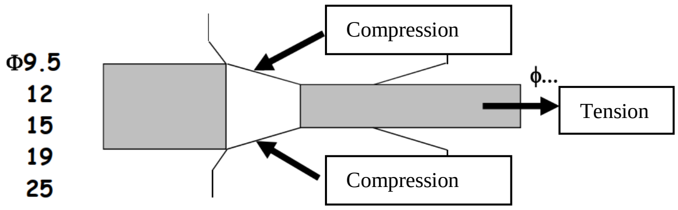

Figure 1. Schematic of the drawing process

For wire drawing, the main element is the die. This is a tool whose principle diagram is presented in figure 2.

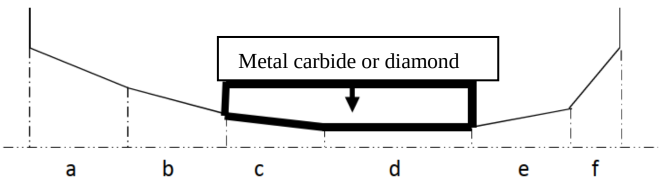

Figure 2. Theoretical shape of the die

The raw material, figure 3, is brought from the raw material warehouse, located in the immediate vicinity of the drawing area, with the help of the overhead crane.

The process of obtaining wires by wire drawing is a very well-known one at present. It is based on the successive passage of the semi-finished product, usually a wire of a larger diameter, made of aluminum or copper but also of fiberglass, through several dies that constitute the main structure of a wire drawing installation. Depending on the degree of deformation designed, these machines can have a greater or lesser number of dies and their arrangement can be done in several ways. The drawing process on these machines always takes place in the presence of a lubricating cooling liquid that greatly reduces the coefficient of friction so that the plastic deformation process can take place in optimal conditions.

During drawing, the main technological property manifested is ductility. This is the property that allows the cold deformation of materials. In the case of cold plastic deformation, there is a change in the crystalline structure of the material. This change is called ecruisation. Annealing changes the mechanical, electrical and physical properties of materials.

Figure 3. Raw material for wire drawing

Drawing is performed on a drawing machine such as the one presented in figure 4.

Figure 4. Drawing machine

A die like the one shown in figure 5 can be used to make the drawing.

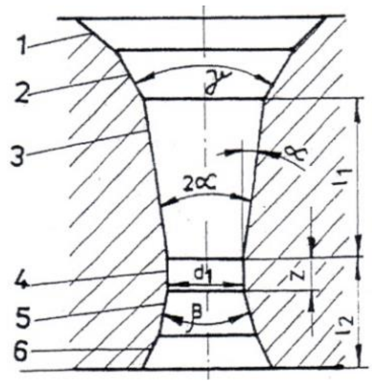

Figure 5. The characteristic areas of the inner geometry of the dies: 1 – entry cone; 2 – lubrication cone; 3 - deformation cone; 4 – calibration part; 5 – release cone; 6 – exit cone; 2α - the angle of the working cone (shooting angle); β- the clearance cone angle; γ - the exit cone angle

An approximate calculation of the force required for drawing is presented by equation 1.

$$F = c \cdot \sigma_m (S_0 - S_1) \quad (1)$$

Where c is the coefficient of friction between the semi-finished product and the mould, - Young modulus of material, S_0 – the initial section; S_1 – the final section. Taking into account that the semi-finished product has the initial diameter d0 = 5.3 mm and the final diameter d1 = 5 mm, an approximate traction force F = 48 E3 N results.

In order to reduce the friction force that appears inside the mold at the interface between the semi-finished product and it, the research that will be undertaken will focus on the use of ultrasonic activation of the mold [1,2,3]. Through this process, an "ultrasonic lubrication" will be achieved [4], which can lead to a significant reduction in the friction process.

The ultrasonic activation of the mold can be done using a principle diagram like the one shown in figure 6 [5,6,7].

Figure 6. Schematic of the ultrasonic activation of the die

Figure 7 presents the ultrasonic transducer whose vibration modes and vibration frequencies will be determined by simulation using the finite element method.

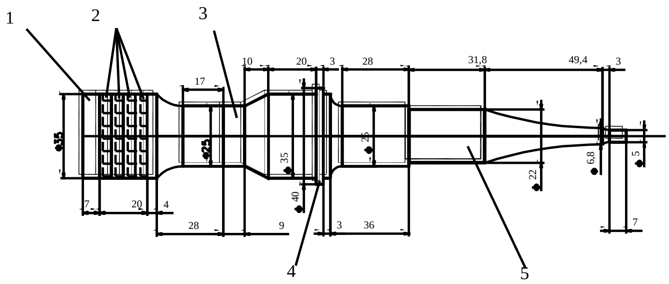

Figure 7. Schematic of the ultrasonic transducer; 1 – reflector; 2 – piezoceramic elements; 3 – transducer body; 4 – nodal flange; 5 – ultrasonic amplifier and booster;

3. FEM MODELING OF THE ULTRASONIC TRANSDUCER VIBRATION MODES

Finite element modeling comes to the help of the research stage in many scientific fields. In the case of simulating and modeling the vibration modes of an ultrasonic system, this proves to be very useful because, in addition to the fact that it helps to understand the shape of the oscillations of the ultrasonic system, it primarily offers the calculation of the vibration frequencies of the system. By knowing these frequencies a priori, there is no need to do very long tests regarding the working frequencies that have an impact on the mold, in this case [8,9,10]. Knowing these frequencies, tuning the ultrasonic generator and using them will be considered.

To find the vibration modes specific to the system, figure 8 presents the model of the transducer shown in figure 7. On this model, the zero displacement of the nodal flange and the application of the electric voltage on the surfaces of the piezoceramic plates were considered as input data [11,12,13].

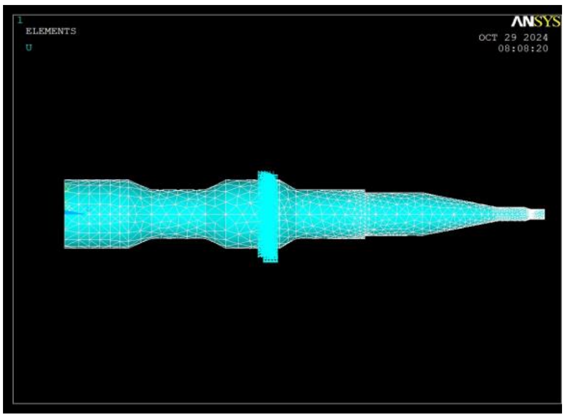

Figure 8. Model of the ultrasonic transducer

Figure 9 presents an enlarged image of the transducer model in which it is embedded in the nodal flange.

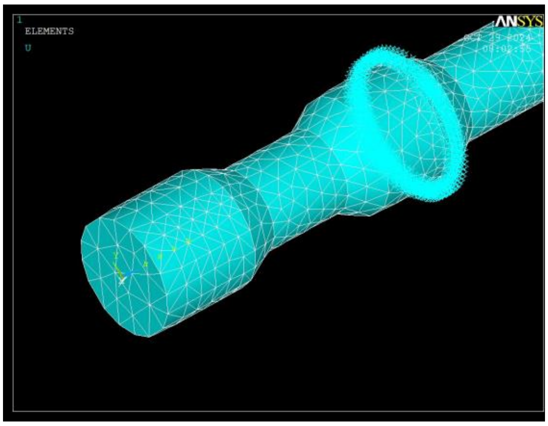

Figure 9. Appling initial conditions: zero displacement on the nodal flenge and electric potential on piezoceramic surfaces

Based on the constitutive equations of the vibration theory, the modal analysis provides the free vibration modes of the ultrasonic system that are desirable in the die activation. In this situation, the highest vibration amplitudes of the system would appear and the energy consumption is minimal. In the ultrasonic range selected for the modal analysis, four free modes of vibration were found. The first of these occurs at the frequency f = 19755 Hz being presented in figure 10. Maximum amplitude vibration is about 12 μm, that corresponds to theoretical expectations.

As can be seen, the design of the entire ultrasonic system was very correctly done so that the only area that deforms is that of the tip of the energy concentrator as seen in the figure 10.

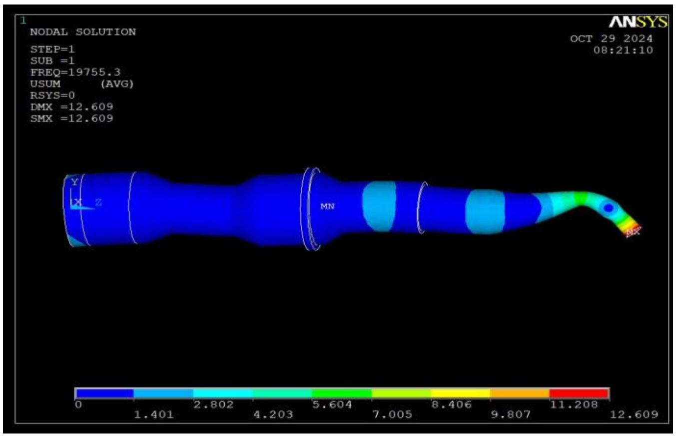

Figure 10. Displacement sum at frequency f = 19775 Hz

It oscillates around the OX axis as shown in the figure 11.

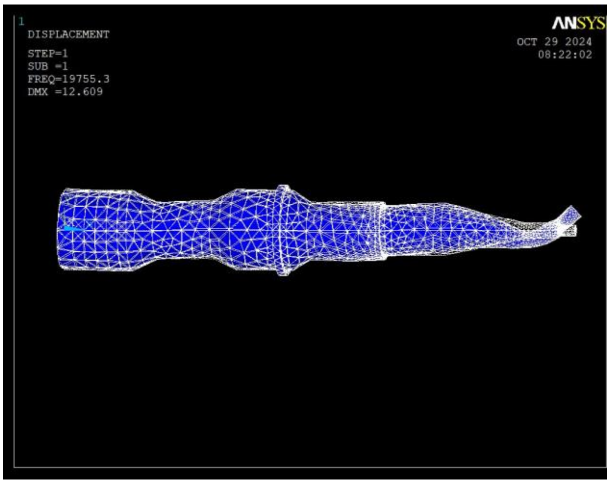

Figure 11. Ultrasonic system oscillation around OX axis at frequency f = 19755 Hz

The second calculated oscillation mode occurs at the frequency f = 19778 Hz. As can be seen from figure 12, this is also done with maximum displacements also in the free zone of the ultrasonic energy concentrator. As is desirable, as with the previous frequencies, the rest of the volume of the ultrasonic energy transducer is not deformed.

This means that especially the area of the piezoceramic discs is not in danger of cracking or destruction.

Secondly, the energy consumption that would be produced by vibrations in these areas would affect the total power of the system by dissipating it in unwanted areas. Also, for this vibration mode the maximum amplitude is 12 μm.

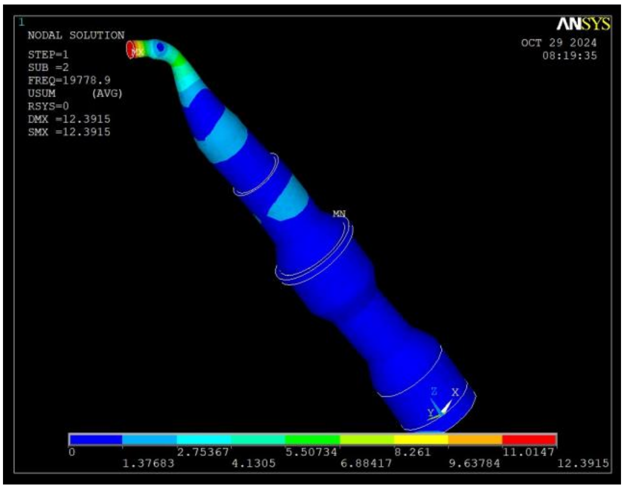

Figure 12. Ultrasonic transducer displacement at frequency f = 19778 Hz

In figure 13, for this vibration frequency, oscillations similar to the first vibration mode can be observed.

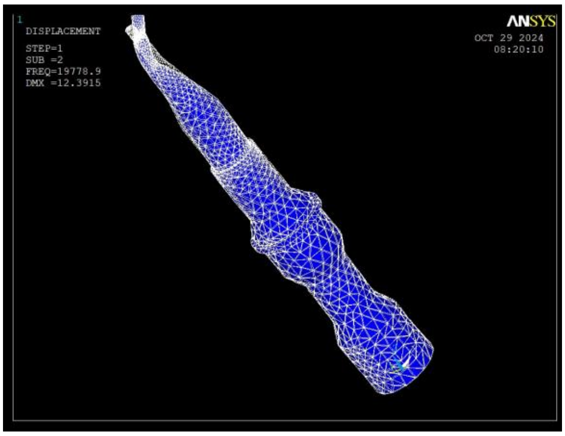

Figure 13. Ultrasonic system oscillation around OX axis at frequency f = 19778 Hz

The third mode of vibration occurs at the frequency f = 20067 Hz. And this mode is very similar to the first two, the amplitude of the oscillations still happening at the top of the vibration concentrator where maximum amplitude is about 8 µm while the minimal of the oscillations are in the whole body of the ultrasonic transducer. This can be seen very well in figure 14.

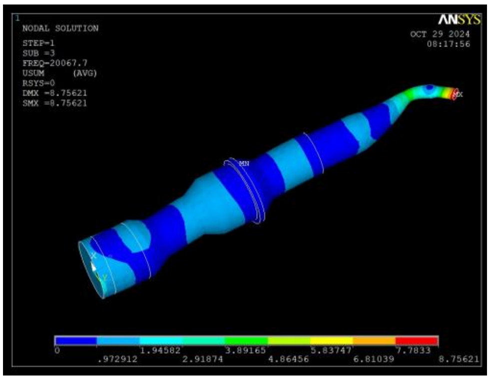

Figure 14. Ultrasonic transducer displacement at frequency f = 20067 Hz

The oscillation mode of the transducer is shown in figure 15. and it is very similar to the other two oscillation modes, occurring around the OX axis and predominantly in the top of the concentrator.

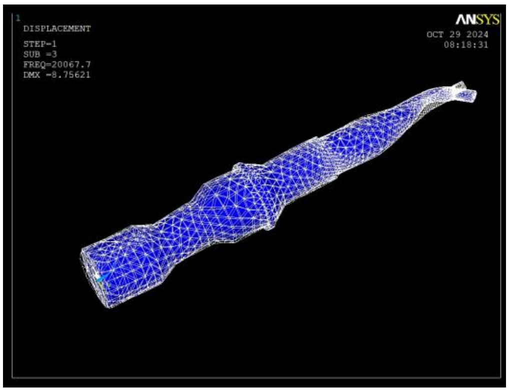

Figure 15. Vibration animation of the transducer at frequency f = 20067 Hz

The last vibration mode calculated is found at the frequency f = 20106 Hz and is again very similar to the first three. The amplitude of the oscillations is 9 mm, being of the same order of magnitude as the first three vibration modes.

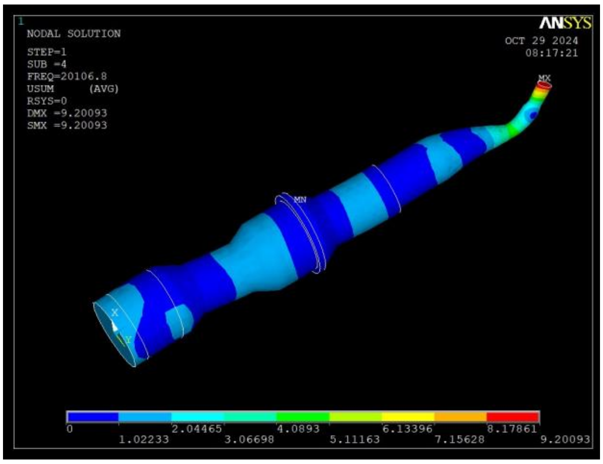

Figure 16. Ultrasonic system oscillation around OX axis at frequency f = 20106 Hz

The animation of the fourth oscillation mode is almost identical to the three vibration modes, also occurring as an oscillation around the OX axis and is shown in figure 17.

4. CONCLUSIONS

The modeling and simulation of the vibration modes of the ultrasonic transducer that will be used to activate the mold used to wire the 5 mm diameter wires shows a very rigorous and optimal design of the entire assembly. This can be seen from the grouping of the vibration modes in a very tight frequency range around the frequency of 20 KHz at the same time as the realization of very similar oscillations in terms of geometric shape.

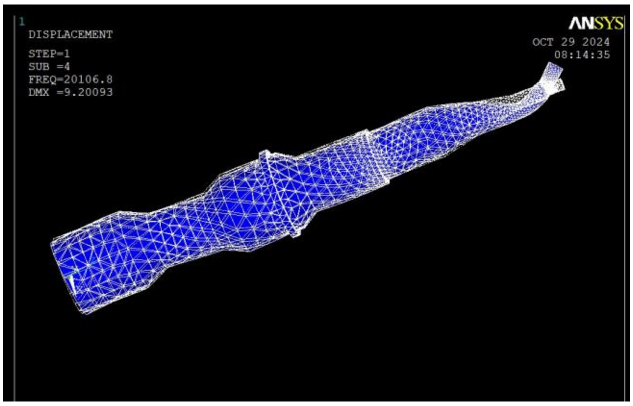

Figure 17. Vibration animation of the transducer at frequency f = 20106 Hz

From the personal experience of the authors who contributed to the realization of this ultrasonic system, it can be said that it is one of the most successful [14]. This is based on the fact that the ultrasonic concentrator produces vibrations that can excite the mold in two directions, the oscillation being complex. In many situations analyzed so far, the oscillations were produced in one direction, which is not an optimal situation, as there are moments when the ultrasonic activation is non-existent and the processes proceed continuously. In this case, the ultrasonic activation of the drawing die is continuous in several directions, which corresponds to the proposed purpose. Next, it can be said that the calculation of vibration frequencies and their finding in a very close frequency range, with very close vibration modes in shape, is beneficial to the experiments that will be concentrated only in that working area of the ultrasonic system.

5. REFERENCES

1. V.C Kumar, I.M Hutchings, Reduction of the sliding friction of metals by the application of longitudinal or transverse ultrasonic vibration, *Tribology International*, Volume 37, Issue 10, Pages 833-840, (2004)
2. Takashi Jimma, Yukio Kasuga, Nobuyoshi Iwaki, Osamu Miyazawa, Eiji Mori, Katsuhiko Ito, Hajime Hatano, An application of ultrasonic vibration to the deep drawing process, Journal of Materials, rocessing Technology, Volumes 80–81, Pages 406-412, (1998)
3. C.L. Yang, C.S. Wu, L. Shi, Analysis of friction reduction effect due to ultrasonic vibration exerted in friction stir welding, Journal of Manufacturing Processes, Volume 35, Pages 118-126, (2018)
4. Kenneth S. Suslick, The Chemical Effects of Ultrasound, *Scientific American* Vol. 260, No. 2, pp. 80-87, (1989)
5. Yi Wang, Bo Qin, Mao Chang Wu, Jian Song, Ping Zou and Ming Hu, Journal: *Advanced Materials Research*, Volume 338, Page 656, (2011)
6. Pingqing Fan and Keshuai Zhou, *Journal: AIP Advances*, Volume 10, Number 1, Page 015054, DOI: 10.1063/1.5128699, (2020)
7. Hanlu Li, Weihao Ren, Lin Yang, Chengcheng Ma, Siyu Tang and Ruijia Yuan, Journal: Proceedings of the Institution of Mechanical Engineers, Part C: *Journal of Mechanical Engineering Science*, Volume 235, Number 19, Page 4337, (2021)
8. Heywang, Walter, Karl Lubitz, and Wolfram Wersing, eds. *Piezoelectricity: evolution and future of a technology*. Vol. 114. Springer Science & Business Media, (2008)
9. R. E. Eitel; T. R. Shrout; C. A. Randall, Nonlinear contributions to the dielectric permittivity and converse piezoelectric coefficient in piezoelectric ceramics, *Journal of Applied Physics 99*, 124110, (2006)
10. S. J. Rupitsch and J. Ilg, "Complete characterization of piezoceramic materials by means of two block-shaped test samples," *IEEE Transactions on Ultrasonics, Ferroelectrics, and Frequency Control*, vol. 62, no. 7, pp. 1403-1413, July (2015)
11. J A Gallego-Juarez, Piezoelectric ceramics and ultrasonic transducers, Published under licence by IOP Publishing Ltd, *Journal of Physics E: Scientific Instruments*, Volume 22, Number 10, (2020)
12. B. Chandra Sekhar, B. Dhanalakshmi, B. Srinivasa Rao, S. Ramesh, K. Venkata Prasad, P.S.V. Subba Rao and B. Parvatheeswara rao, Multifunctional Ferroelectric Materials, *Piezoelectricity and its applications*, Submitted: October 9th, 2020 Reviewed: January 22nd, 2021 Published: September 8th, (2021)
13. Aabid, A.; Raheman, M.A.; Ibrahim, Y.E.; Anjum, A.; Hrairi, M.; Parveez, B.; Parveen, N.; Mohammed Zayan, J. A Systematic Review of Piezoelectric Materials and Energy Harvesters for Industrial Applications. *Sensors* (2021)
14. Aabid, A.; Parveez, B.; Raheman, A.; Ibrahim, Y.E.; Anjum, A.; Hrairi, M.; Parveen, N.; Zayan, J.M. A review of piezoelectric materials based structural control and health monitoring techniques for engineering structures: Challenges and opportunities. *Actuators,* 10, 26 (2021)