

THE ROLE OF IMPROVED MANUFACTURING TECHNOLOGY IN THE DESIGN OF MEAGER TRANSDUCER ARRAYS

¹E.VENKAT REDDY, ²S.CHAKRA SIREESHA, ³S.RAM MOHAN REDDY, ⁴A.RAVEENDRA

^{1,2&3}Asst.Professor, Department of Mechanical Engineering, Malla Reddy Engineering College (Autonomous), Maisammaguda(H), Gundlapochampally Village, Secunderabad, Telangana State - 500100

⁴Assoc.Professor, Department of Mechanical Engineering, Malla Reddy Engineering College (Autonomous), Maisammaguda(H), Gundlapochampally Village, Secunderabad, Telangana State - 500100

Abstract

Large two-dimensional (2D) arrays offer very promising prospects as an analysis tool due to their capability to obtain information of volumetric spaces. However, this kind of development has major drawbacks. The main challenge comes from the large number of elements required to achieve an acceptable image quality. The sparse arrays have been proposed as a compromise solution between the number of active elements and dynamic range. Although we can find in the literature a lot of examples about sparse arrays models, there is a significant lack of experimental prototypes. The main reason for this is that the manufacturing process is expensive and complex. In order to address this problem, the capabilities to develop structural parts of sparse arrays of manufacturing process based on Additive Manufacturing technology have been analyzed in this paper.

INTRODUCTION

Nowadays, it is widely accepted that large two-dimensional (2D) arrays offer very promising prospects as an analysis tool due to their capability to obtain information of a volumetric space. However, to avoid grating lobe formation, the distance between transducers in the array element distribution is limited to $\lambda/2$. Therefore, large 2D matrix apertures involve a high number of elements. This issue leads to some challenges at several levels: (i) manufacturing level, because the large number of elements involves also cables, shield, matched filters, etc; (ii) signal conditioning level, because the small size of the elements, the contribution of individual elements is very low and offers poor SNR (low radiation area

and low sensitivity); (iii) system control level, because of the complexity of acquiring, processing and managing a large volume of data; and finally, (iv) the economic level, because of the high cost associated with the transducer and the systems. Although, micromachined and microelectronic manufacturing techniques reduce some of the manufacturing problems, allowing the development of high densely populated apertures [1], some of the challenges identified are still unsolved or involve a huge bunch of resources. In any case, some solution to these issues involves a high cost and a high degree of uncertainty that makes it difficult to be justified.

Consequently, there is a reduced offer of both commercial 2D transducer and associated instrumentation. Furthermore, the systems identified in the literature are mainly laboratory instruments. In this sense the reduction of active elements in the aperture, by sparse array design is an interesting solution for the development of volumetric imaging systems. Therefore, the main challenge in array design is determined by the number of elements necessary to achieve acceptable image quality. In the literature we can find a lot of examples of sparse arrays [2], [3]. However, the number of experimental prototypes is very low [4]. The main reason for this is that the manufacturing process is expensive and complex. In order to address this problem, the capabilities to manufacture structural parts of sparse arrays based on Additive Manufacturing technology [5] and the consequences in the transducer behavior have been analyzed in this paper. The results show that Additive Manufacturing gives an opportunity to array designers to develop low cost and risky proof of concept.

Additive manufacturing (AM), or 3D printing, builds objects layer by layer using 3D modelling data. AM has been explored from rapid prototyping to tooling that leads to direct production. More importantly, AM can be used to integrate with CAM (computer-aided manufacturing), CNC (computer numerical control) and CAD (computer-aided design) for 3D printing objects.¹⁻⁴ AM is applied everywhere from biomedical applications to aircraft design and is being slowly explored for applications in the oil and gas industry. The materials used in AM include polymers, metals, ceramics

and their composites; however the materials for AM are still limited. For instance, in some cases CNC machining is needed as, sometimes, the dimensions of the spare parts to be built can be larger than available AM printers can cope with. Rapid prototyping may not be a good answer for all instances as CNC machining could also be required.³⁻⁵ In the past few years, AM has played a key role in the oil and gas industry by promoting the engineering nozzles produced by the GE company.⁶ Although AM has significant opportunities in the oil and gas industry, the truth is that real companies have become slower to take them. However, major oil and gas service companies have invested in AM and have completed some successful pilot projects.^{7,8} AM is potentially capable of enabling the design of products with complex structures with reduced cost and waste and could also reduce the overheads associated with documentation and production planning.⁹ AM technology produces parts with fewer materials compared to conventional technologies and provides a quick response to demand for spare parts.

Proposed method

The main challenge comes from the large number of elements required to achieve an acceptable image quality. The sparse arrays have been proposed as a compromise solution between the number of active elements and dynamic range. Although we can find in the literature a lot of examples about sparse arrays models, there is a significant lack of experimental prototypes. The main reason for this is that the manufacturing process is expensive and complex. In order to address this problem, the capabilities to develop

structural part of sparse arrays of manufacturing process based on Additive Manufacturing technology have been analyzed in this paper.

Methodology

II. SPARSE ARRAYS DESIGNED FOR PROTOTYPING

At first, a sparse array is designed to accomplish the specifications, which are related to lateral resolution, dynamic range or number of active elements. However, in order to develop a solution suitable for manufacturing some other considerations should be done, like cable distribution and the supporting structure. In this sense it is important also take in account the manufacture procedure that is going to be followed.

Fused Deposition Modeling (FDM) techniques are suitable to produce cost-effective structural components. The materials used by these techniques are plastics that can be manipulated easily and, in order to implement arrays, show interesting mechanical properties. For this case we have considered acrylonitrile butadiene styrene (ABS), polylactic acid (PLA) and thermoplastic polyurethane (TPU). Nowadays, 3D printers have good link with Computer Assisted Design tools that help to design tridimensional structures. Basically, the array element is constituted by three components: the piezoelectric component, the cable that provides electrical connection and the backing. A. Array element structure The Figure 1 describes the structure of a single element. The manufacturing process is divided in two stages printed as separated parts. The first stage is where the

piezoelectric component, the cable and the electric contact are located. The manipulation degree required at this stage is very high. In the second stage, the main part of the backing structure is placed, optionally including a dispersal space.

Two piezoelectric components have been considered for the testing purposes: 1MHz PZ27 ceramic (Ferroperm™) and 1.5MHz 1-3 piezocomposite (Smartmaterials™, 851 material, Dice and Fill 65%). These two components were diced in order to achieve the element dimensions and their electrical impedances were evaluated. The results show that piezocomposites maintain its resonance response meanwhile the PZ27 has reduced its resonance frequency.

The cable is located near to the element and guided through a channel across the aperture structure to the outer shell of the plastic structure. To place it, we made use of supporting point and heat to fix it. In order to make contact between both elements, conductive epoxy was used. This epoxy layer constitutes the first part of the backing structure. Therefore, backing epoxy is doped with tungsten to match the impedance of the conductive layer. If the backing column needs to be more loaded, conductive epoxy could be replaced by silver conductive paint.

The material used to manufacture the first stage can be used to minimize the mechanical crosstalk between elements. In general, all materials used (ABS, TPU and PLA) show good mechanical response. However, TPU is less capable to avoid lateral oscillation. ABS has been discarded because of the wide use of acetone to clean epoxy.

SPIRAL SPARSE ARRAYS

To analyze the capacities of FDM to develop structurescapable of enclosing a dispersed matrix, a simple set of specifications have been considered as proof of concept: lateral resolution less than 1:5_, no more than 64 elements, operationfrequency of 1.5MHz and a dynamic range higher than 30 dB.If the Fermat spiral distribution is analyzed for a diameter of48_ and 64 elements, three different angles provide solutionsaround them than can be considered as viable: 84_, 95_ and 140_. Therefore, in this case the selection is addressedby manufacturing considerations like cable location, routingand how backing columns are distributed. In this sense, toFig. 2. Top: electrical impedance of 1:5 _ 1:5 mm PZ27 (1MHz). Bottom:Electrical impedance of 1:5_1:5mm 1-3 piezocomposite (851 material, Diceand Fill 65%, 1.5MHz)reduce as much as possible the mechanical interaction betweenelements it is interesting to isolate each backing columns.

These considerations point to the angle 140_ as the moreadequate for our purposes.The simulated pulse-echo response of the aperture showsa lateral resolution of 1:2_ and a dynamic range of 33 dB(Figure 3 Bottom).

Results

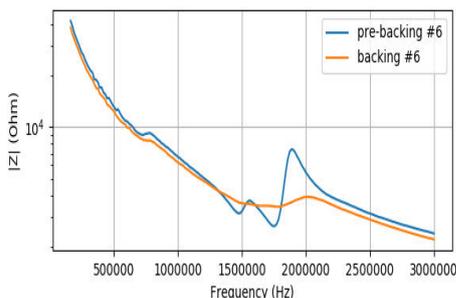


Fig. 8. Electrical Impedance of the element number 6. In blue previous tothe backing insertion. In orange after the backing insertion.

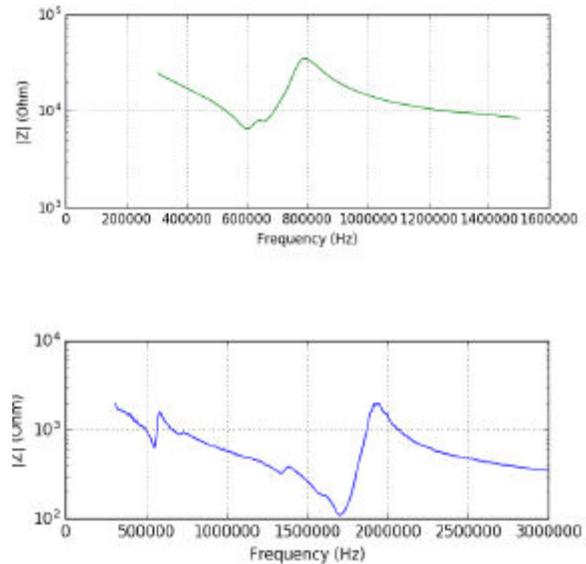


Fig. 10. Temporal response and Power Spectral Density of four elements ofthe aperture. Left: elements 34 and 62. Right: elements 6 and 16.

CONCLUSIONS

In this work a sparse array of 48_ diameter and 64 elementsbased on a Fermat spiral distribution has been designed andmanufactured. In order to make it, a novel technique has beendeveloped based on FDM. This technique has shown to bevery versatile and cost effective. In this sense this techniqueseems to be adequate for the development of risky proof-ofconceptand can support an improvement of the arrays designtools.

Future scope

As a matter of fact, AM has brought many innovations and opportunities in various industries, mainly medical, aerospace, and automotive. AM helps effectively with cost and time-saving, reducing complexity, rapid prototyping, and highly decentralized

production. However, besides the several advantages of AM technology, there are also some barriers against its quick growth, such as size limitation, production time, limitations of materials, and machine and production costs. AM is also in the group of sustainable and efficient production processes in the field of manufacturing which helps with resource-saving and environmental protection. The sustainability studies show a considerable reduction in material waste and fuel consumption as two principle benefits in AM. In fact, eco-design in AM provides this opportunity that the environmental issues fundamentally be considered in each design and fabrication stage, accordingly, various eco-design tools, e.g., life cycle analysis (LCA), can be applied for evaluating the environmental impact of products

REFERENCES

[1] Satyanarayana, P. and Subramanyam Pavuluri, D.A., 2013. PARAMETRIC MODELING AND DYNAMIC CHARACTERIZATION FOR STATIC STRENGTH OF STEAM TURBINE MOVING BLADES. International Journal

of Innovative Research in Science, Engineering and Technology, 2(7).

[2] PAVULURI, S. and KUMAR, D.A.S., 2013. „ Experimental Investigation On Design Of High Pressure Steam Turbine Blade““. International Journal of Innovative Research in Science, Engineering and Technology, 2(5), pp.1469-1476.

[3] Sreenivas, P., Kumar, A.S. and Subramanyam Pavuluri, D.A., 2013. Investigations on transient dynamic response of functionally graded materials. a a, 1, p.2.

[4] Pavuluri, S., Rajashekar, B. and Damodhar, B., Process of Press Tool Design and its Manufacturing for Blanking Operation.

[5] KUMAR, S.S. and SUBRAMANYAM, P., DESIGN AND WEIGHT OPTIMIZATION OF OIL PAN BY FE ANALYSIS.

[6] PAVULURI, S. and KUMAR, D.A.S., 2013. „ Experimental Investigation On Design Of High Pressure Steam Turbine Blade““. International Journal of Innovative Research in Science, Engineering and Technology, 2(5), pp.1469-1476.