Comparative Study on Simulation Software in MEMS Design: A Survey

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Abstract **- MEMS is a combination of mechanical and electrical components to create devices in micro scale range. The cost of production can be reduced by proper simulation there are many software tools are available for MEMS design the selection of tool depends on the customisation of the design and the range of geometry. This paper will summarise the technical features of all available software tool for MEMS design. The paper also contains the key points to be considered in the software while selecting as a tool for MEMS design and also details of the basic features available in all MEMS designing tools. It has been observed that if the design has particular physics and geometry the appropriate software must be selected. If we have the target of fabricating the device then software with virtual fabrication feature must be selected.**

Index Terms **- MEMS, MEMS simulation tool, COMSOL software, coventovare software, Ansys, intellisuit software, FEA (finite element analysis tool).**

1.INTRODUCTION

The journey of electronics has been started by the invention of bipolar junction transistor in 1948, BELL LABORATORIES is the pioneer for the invention of transistor. as continuation of this journey BELL labs has invented silicon transistor in 1954. During the same time smith [15] coined the piezo resistive phenomenon in semiconductors. This piezo resistive process in semiconductor is the beginning of MEMS research. The research journey of MEMS has been started with the first prototype of pressure sensor in 1961. MEMS devices can be used as actuators sensors and switches, the key techniques used in MEMS are capacitive, piezoresistive, thermoelectric and resonant principles. MEMS sensors has its applications in automobile industry, biomedical industry, defence, gas sensing, inkjet printers etc…MEMS sensors are made of different materials like semiconductors, ceramics, plastics and silicon etc... and most of the manufacturing methods are bulk micromachining and surface micro machining.

MEMS simulation and design is interdisciplinary concept which involves the knowledge of both mechanical and electrical engineering. In biomedical application the designer must have knowledge of human anatomy also. Generally, MEMS design process is combination of design, fabrication, optimization and testing. Before fabrication we need to confirm that whether the design meets our expected goals or not. For this reason, we need simulation software once simulation meets the expected geometry then it will be given for fabrication. This saves the cost of production and reduces the wastage of production.

Theoretical modelling and numerical modelling are the two methods that we can use for MEMS basic modelling [11]. Usually, theoretical modelling is preferred for simple designs. Numerical modelling is used for complex design with complex geometry this method is most commonly used modelling method for MEMS design. Most famous numerical method using for MEMS design is finite element analysis. FEM analysis helps to model the complex boundary conditions. Use of finite element analysis significantly reduces the cost of device because avoids unnecessary prototyping. Small variations will be there in the outputs of different FEA tools [10] based on different boundary conditions.

2.SIMULATION OF MEMS

In MEMS simulation the design was started as a first step, and then the selection of materials will be done after this process boundary conditions will be decided finally simulation result will be displayed by loading these conditions. Figure 1 illustrates the process flow for FEA analysis in MEMS. Initially the problem

definition will be done, then model is created according to the required geometry then selection materials will be done, then boundary conditions will be done and meshing procedure will be done. This procedure may vary from software to software, after these procedures results are simulated. Once we get the desired results in simulation, we need to display the result and then we need to give to fabrication. The fabrication can be done in virtual fabrication tool in that it should undergo all fabrication design check rule. After satisfying all design rule check it can be sent to physical prototype manufacturing.

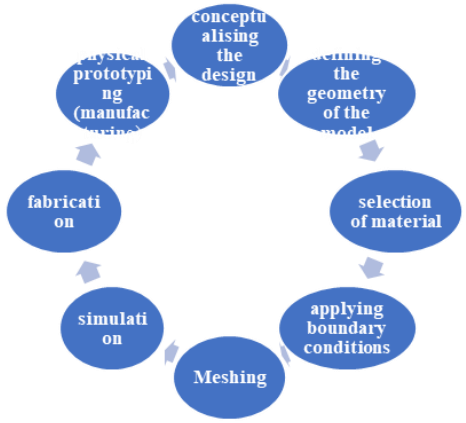

Fig 1. MEMS FEM tool process flow.

MEMS simulation is can be summarized with three phases preprocessing, analysis and post processing [7]. Deciding geometry, material selection, boundary selection and meshing these all covered under pre-processing. Assigning the theoretic assumed valued to the designed geometry and analyzing the response by trial-and-error method will be done under analysis phase. Post processing consists of display of results and fabrication rule check. Post processing step may involve the graph of force, displacement, deflection plots. If the device is completely made using MEMS simulation software, then it should be analyzed with software which analyze the output of MEMS device concatenated with IC. Figure 2 illustrate the MEMS simulation phases.

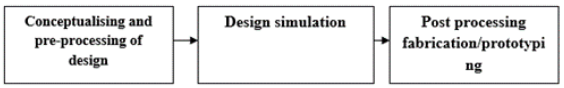

Figure 2. Simulation Phases

A.Pre-processing of MEMS simulations

Sometimes when the design geometry is too complex we use other softwares to create the model and then it will be imported to MEMS design software. Most commonly used software for creating geometry is Auto cad, MathCAD.

B.MEMS simulation

Most commonly running softwares for MEMS design in market are Ansys, COMSOL, Sugar, intellisuit, coventor, and MEMS soft and MEMS pro. Table 1 summarize the comparative features of above mentioned softwares.

ANSYS

Ansys software was developed in 1970 by Canonsburg [19] in Pennsylvania. This software is used to monitor the product lifecycle management it can also be used for structural analysis, heat transfer and fluid mechanics etc. some of its products has 3D design, semiconductor analysis and embedded board compatible software.

It has GUI and command space interface it gives feature to expand the structural design to test the explosion, penetration analysis and fatigue analysis. It can be legible to perform linear as well as nonlinear analysis. It has ability to analyze coupled field behaviors and complex math operations as well as branching and looping.

Ansys software process flow has material selection, geometry design, meshing and boundary conditions loading and finally results display and analysis. Biosensors [1], accelerometers [3], cantilever structure [18] are few examples of Ansys simulations. Student version software is open source which is available in ANSYS website. This software is widely used by researchers and industries. Some of the major leading companies like Benalty, Siemens, university of Liverpool, HCL, ford, Hp, TVS etc…

INTELLISUIT

Intellisuit software was developed in 1991 in Boston [22]. In 1995 it has released its first version. It can become a complete tool for MEMS simulation. It can be used as top-down approach or bottom-up approach for design. Intellisuit has simulation, packaging, device analysis. As all the features available in single software this becomes very easy for designers to communicate with single platform.

The popular modules provided by intellisuit are design suit, clean room MEMS analysis, fast field thermo electron mechanical module and system synthesizer. Piezoelectric pressure sensor [16], Bio MEMS [5],

micro actuator [2] are some examples of intellisuit simulation.

In some specific cases design rule check must be done for fast and accurate results. Some specific companies using this software is Nikon, Stanford university, Hitachi, apple, and Honda.

COMSOL Multiphysics

COMSOL software was developed in 1986 with its head office situated at missachutters [20]. It is the simulation software for all kind of designs in engineering field, research field and manufacturing. It is used for structural mechanics, acoustic modules and fluid mechanic models. It can be interfaced with (CAD and MATLAB). In this software material library is very huge and allows user to select different type of material. We can also define new material. User can use the huge database of material property; library and can import the property of materials. It has ready files for coupling effect analysis and modelling it has ability to do metaphysics analysis of surface contact.

In COMSOL initially geometry will be added, the physics will be defined. After that meshing will be done finally result analysis will be done. COMSOL support many file formats and output can be exported to excel directly. There is a possibility to import directly to other software using interface links. Electrostatic cantilever [17], capacitive pressure sensor [13] are some examples of COMSOL design. COMSOL is used by both researchers and industry. COMSOL fermi lab, siemens, Huwai, Nokia, BELL lab use COMSOL for their design.

COVENTOR

Coventor was developed in 1996, its head office is situated at reileigh, north corolina[21]. The major products of coventor are SEMmulator and coventor MP. SEMmulator accommodates the virtual fabrication environment coventor is used for mems simulation. It is the most widely used software for mems simulation.

It uses abacus, fluent, and 3D flow for design calculation. It has 4 modules they are architect, designer, analyzer and system builder.

Architect divide the evaluation of MEMS design. Designer helps to create layout, mask and generate 3D model. Analyzer has library for electronics, mechanical and thermal process models. System builder created files which generate output model. These outputs can be exported to other software like cadence, MATLAB etc.

MEMS+ helps the user to inculcate the mems design with CMOS circuits (IC). It facilitates the user to analyse the mems and CMOS design in cadence tool. MATLAB and Simulink gyroscope [4], MEMS comb structure [12], are some examples for the coventor design. DALSA and FAB are well known MEMS foundries they use SEMmulator for design and simulation and failure analysis. This software tool is used by both researcher and industrialist. Texas instrumentation, IBM, SONY, TOYOTA, HUNDAI, HONEYWELL are using this software for their design.

MEMS PRO

Mems pro was started in the year 2004 in north America Santa Clara, USA [25]. Mems pro has both the features of MEMS and IC design tools. It has the feature of mixed analog and digital circuit level behavior simulation. It allows automatic mask layout generation from ANSYS tool it supports virtual fabrication environment also.

This software includes MEMS modeler, MEMS verification, Layout design and foundry modules. MEMS modeler perform behavioral model, layout design helps in customizing the design, MEMS verification models helps for the design rule check used by foundry. 3D modeler gives the 3D view of MEMS device. GDSII, CIF, EDIF, and DXF are the different file formats that support MEMS PRO simulation. Accelerometer design [9], capacitive gyroscope [8], are few examples of simulation works using MEMS PRO software tool.

MEMS SOLVER

MEMS solver is analysis tool for specifically designed for MEMS. It has vast library models which are specifically used for MEMS. The uniqueness of this software is user can only give basic design geometry layout, meshing, boundary conditions everything will be done by software only. It has special feature of graphical representation of result, programming skills are not needed with this software. It has five modules sensing , actuation, data analysis and mechanics.

SUGAR

It is the open-source software tool for design and analysis of MEMS device [24], this software is most

commonly used for new designs in initial phase. It is text-based programming and it can be interfaced with MATLAB. This software is used for frequency and deflection analysis.

Software for post processing of MEMS device

MEMS simulation results are further processed with IC, microcontroller, and display devices. Commonly using software for post processing of MEMS simulation results are Simulink, VHDL, Verilog, MEMS+, cadence and tanner etc... user should decide the interfacing tool according to customized requirement.

Important points to be considered for selection of MEMS simulation Software

As per the experienced survey following points are summarized as the key points to be considered while selecting the MEMS designing tool:

- Every MEMS simulation software has basic feature user has to check the design geometry and he should decide whether this geometry is compatible with the software feature or not.
- It will be always good to check whether the software has different physics model or not. If the software has multi physics then the software is capable of supporting many physics at time.
- The user should check about the meshing support so that it should allow different element size mesh for different parts analysis. Ex: if liquid is flowing in rectangular bending pipe, we should calculate pressure at the bending edges. For such application local meshing facility must be there in software.
- User should check about the accuracy of the design simulation by comparing with real time fabrication and manufacturing then he should evaluate the software.
- The user should check whether the software is user friendly or not. And it should contain huge tutorial examples.
- Important key factor that the user should notify is whether output of MEMS software is easily interpretable and easily exportable file to some other software or not. If they generate very complex file its better to select user friendly software.
- Parametric analysis this is the very important feature that the MEMS software should have this feature facilitates the user to change the input parameters instantly to change the design. This facility is there in very few software among the software we discussed. This feature helps for optimization time and reduces the hectic for the designer.
- If user has goal of fabrication, then he should he should opt for the software having virtual fabrication.

FEATURE	COMSOL	ANSYS	COVENTOR	INTELLISUIT
External interfacing	Excel, inventor, solid works, Revit, AutoCAD, Design Module, ECAD, MATLAB, HTML.	Simulink, Excel, CAD, MATLAB, SAT, CAD.	Layout editor, cadence, SPICE, MEMS+.	Cadence, Mentor, synopsis, Agilent, touchstone, Simulink.
File format	IPT, IAM, IGES, AVI, PNG, MP4.	CDB, RST, RMG, ASCII, PLOT3D.	SAT, IGES, and STEP.	IGES, ABAQUES, PLT, TOUCHSTONE.
User friendliness	✓✓	✓	✓✓✓	✓✓
Modelling feature	✓✓✓	✓	✓✓	✓✓
Simulation feature	✓✓	✓✓	✓✓✓	✓✓✓
Own Geometry designing feature.	✓	×	×	×
Virtual fabrication feature	×	×	✓✓	✓✓

Table 1 MEMS simulation user friendly feature comparison

3. RESULTS

The list of software discussed above efficient for MEMS design and analysis. Among them COMSOL provides best CAD designs, easy integration of multiple modules, virtual prototyping, user guide all are available with COMSOL which makes it very easy to use. The difficulty with COMSOL is it's very

difficult to troubleshoot the error and memory required for simulation is very large.

Ansys is most efficient for explosion test, drop test, penetration analysis, fluid mechanics and nonlinear problems modelling. Ansys is not efficient for material property analysis because such a analysis is a function of multiple variables.

Intel suit is most advanced high-end tool for MEMS simulation because it has the capability of executing real time simulation. Intel suit and coveter both has virtual fabrication facility. Intel suit is best recommended tool for process simulation and coveter is best recommended tool for system level simulation.

4.CONCLUSIONS

This present paper explores the comparative study on technical features of available software for MEMS simulation. It also discussed the factors that are to be considered while selecting the software. All the software has its own specificity and features but the user has to decide according to his need and customized demand. Availability, ease of use, cost these are the different factors to be considered. User has to go through feature study before selecting the software. Example if the software is purchasing for research in educational institute, they prefer only simulation parameter so they can opt for software with simulation only (example Ansys, COMSOL). If the software for industry they should opt for software having virtual fabrication facility example Intel suit and coveter.

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