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A design simulation system for microstructures

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ABSTRACT

This paper describes some of the results of the MASS project to develop an integrated environment for the analysis and simulation of microsystem/microstructure devices, components and processes.

The systems comprises tools to enable the designers of microsystems to shorten the time to design new products, reduce the cost of development, increase quality and reliability and finalise product specification at the design stage to eliminate the need for expensive prototypes.

Application of the system and comparisons with experimental data are presented.

1.0 Overview Of The System

Microsystems, microcomponents and microstructures in addition to electronic components are all used in the engineering industry as part of systems and micromechanical components which, for example form, parts of integrated sensors or microactuators and offer new possibilities to signal processing and sensors.

The objective of the system was to provide the designers of such systems with an integrated set of automated tools to assess the functionality and suitability of the design. The diagram shown in Figure 1 provides an overview of the system describing the different aspects of its design. The system has been designed to be able to run of both UNIX and PC computers.

The aspects of the different elements of the system are described below.

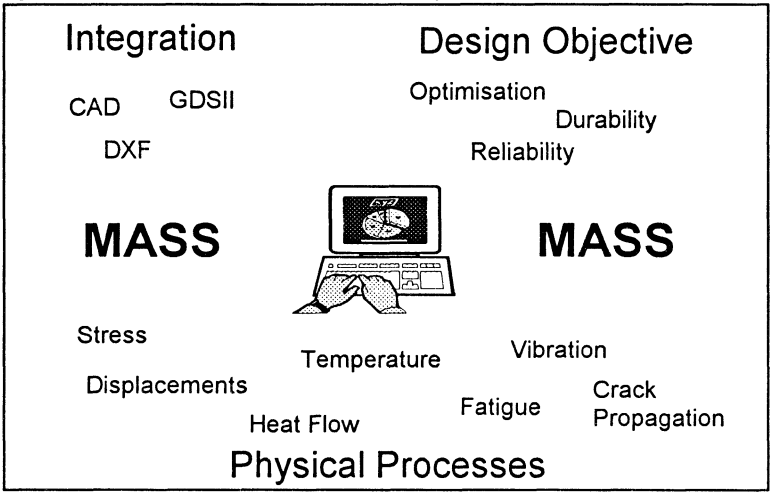


FIGURE 1. Overview of MASS concept.

2.0 Integration

To enable an enterprise or group of engineers to work on a common project involving differing engineering specialities it is essential that design information can be exchanged easily. The solution adopted was to use standard product description standards such as IGES, DXF and GDS II to enable data on designs to be easily imported prior to the simulation of its function. (It is intended to add support for standards such as STEP at a later date.)

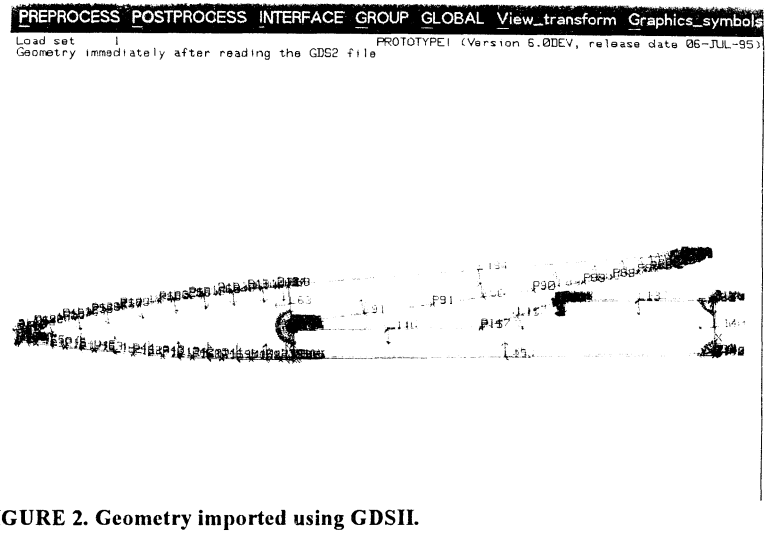


FIGURE 2. Geometry imported using GDSII.

An example of this integration is shown in Figure 2 where the geometry imported from the GDSII file is displayed. It is essential that such interfaces are "smart" as it is often the case that standards defined for one application (ie in this case electronic CAD) present difficulties for mechanical analysis. For example, the geometry from GDSII consists of a large number of short lines, ie facets. The system can therefore automatically assemble the lines into more meaningful geometric entities suitable for an analysis model. Figure 3.

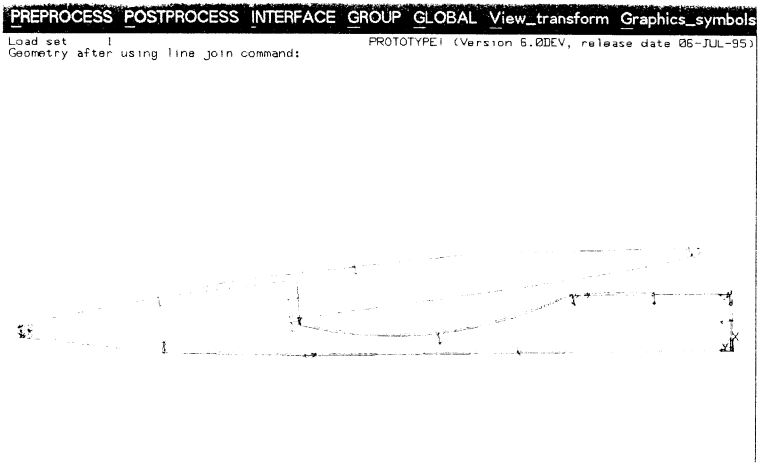


FIGURE 3. GDSII geometry converted into analysis geometry.

In this way the system is capable of importing geometry from most if not all CAD tools and systems.

3.0 Errors in Manufacturing

A number of special features have been incorporated to enable the designer to obtain rapid answers to design questions. For example if the process is susceptible to errors in the shape due to the process of manufacturing their impact can be quickly assessed.

An application of this technology would be to determine how the stiffness of the optical connector (Figure 3) changes with an error in its shape caused by shrinking. Shrinkage (or enlargement) can be volumetric (ie all of the geometry scaled typical of ceramics) or optical (ie the external surfaces grow or shrink a defined amount).

In this application the impact on the stiffness of a 5% volumetric shrinkage or

enlargement is predicted. Table 1 shows the results of the calculation.

MODEL	MAX DISPLACEMENT
Design Geometry	**5939**
5% Shrinkage	**+ 1.74%**
5% Swelling	**- 2.77%**

TABLE 0. 1 Impact of Manufacturing Tolerances on Optical Connector

4.0 Automated Analysis

An essential requirement of a systems which is to be used by non expert analysts is the ability to automatically control the accuracy of the analysis or simulation. There are many sources or error which can impact the accuracy of simulation results. These vary from errors in geometric shape, loading, material properties, boundary conditions and the model idealisation itself. These errors focus on how well the model of the structure represents the actual product itself.

The other source of error is the actual numerical process itself. A major objective has been to reduce or eliminate this source of error. This has been achieved by combining the simplified modelling of the boundary element method with an adaptive numerical strategy.

The boundary element method requires only a boundary description (or surface model) in order to perform an analysis. This substantially simplifies the process of defining the model in terms of elements and reduces the number of elements required. The surface model requirement also simplifies the link to CAD systems.

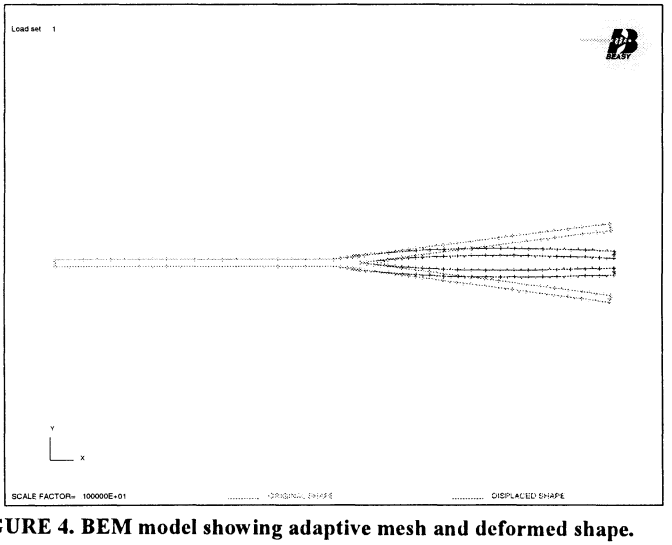


FIGURE 4. BEM model showing adaptive mesh and deformed shape.

A boundary element model of a microstructure is shown in Figure 4. The structure has been analysed using the adaptive analysis procedure incorporated in the system. This applies a combined h and p adaptive strategy to reduce the errors in the model until the required accuracy has been achieved. Combining h (reduction of element size) and p (increase of element order) has been proved to be the optimum strategy. Figure 5 shows the stress distribution and the adaptive refinement can be clearly seen near the branch in the structure.

5.0 Experimental Validation

The new tools developed have been validated by comparing with analytical solutions and most importantly by performing tests on microstructures. The testing of the structures is described in Ref [1].

Figure 6 shows one of the tests carried out on a vibration sensor. The figure shows the first mode of vibration predicted by the system. [Note only a boundary mesh is used.] The results of the experimental and numerical tests are shown in Table 2.

TABLE 0. 2 Natural frequencies of Accelerometer Hinge

MODE	MASS PROJECT	FEM	EXPERIMENTAL
1	502.95	503.09	458
2	10670	10879	NA
3	96009	NA	NA

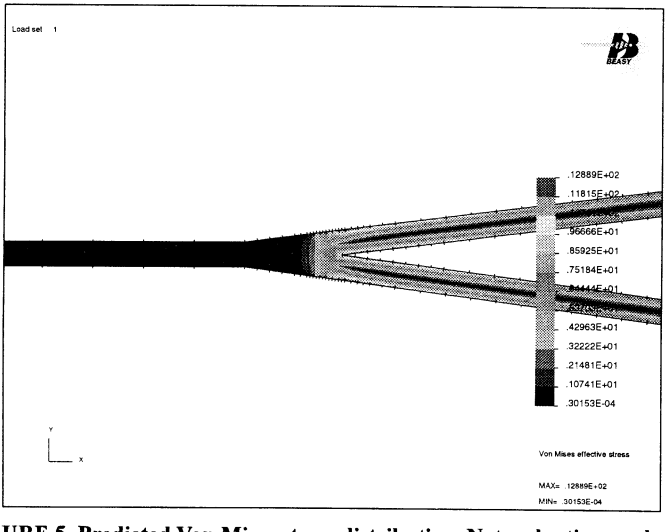


FIGURE 5. Predicted Von Mises stress distribution. Note adaptive mesh refinement.

As can be seen the results compare well with FEM but there is a larger variation

with the experimental data. However this difference is within the experimental tolerance due to the difficulties in accurately measuring the geometry of the hinge. (For example the thickness of the thin section of the hinge is 8 microns.) Other experimental data gives much closer agreement as reported in [1].

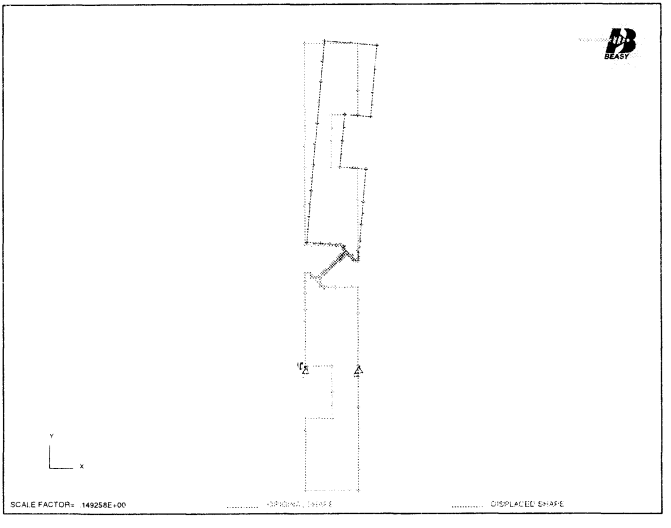


FIGURE 6. First mode of vibration of the accelerometer.

6.0 Life Prediction, Durability and Reliability

As can be seen from the previous discussion experimental validation of the performance of microstructures is extremely difficult and subject to large experimental errors. Therefore a conventional engineering approach involving design, prototype and test is inadequate and expensive. A significant effort has therefore been made to provide tools to enable the designer to assess the life of the microstructure and assess the impact of damage introduced by the manufacturing process and during the life of the structure

An interesting study is to assess the impact of a defect causing a small crack in the vibration sensor. Figure 7 shows the deformed shape of the structure. The designer has specified that a small crack has occurred and the system has automatically computed how the crack will propagate (Figure 8) and how many cycles it will take until the structure fails. (Figure 9). The impact of the damage on the stresses and deformation of the structure is also predicted.

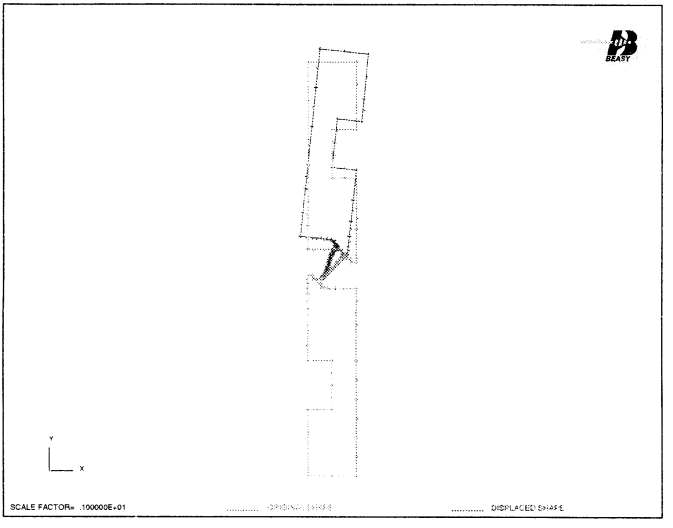


FIGURE 7. Deformed shape of accelerometer.

7.0 Conclusion

The development of a system for the design and simulation of microsystems and microstructures has been described.

Links to CAD systems have been established and tools for assessing the impact of manufacturing processes on the performance of the structures have been developed.

A high degree of automation has been introduced into the simulation process by using the boundary element method coupled to hp adaptivity.

The tools and techniques have been verified against experimental tests performed on microstructures.

Finally techniques have been developed to assess the impact of manufacturing faults and to estimate in service life

8.0 Acknowledgment

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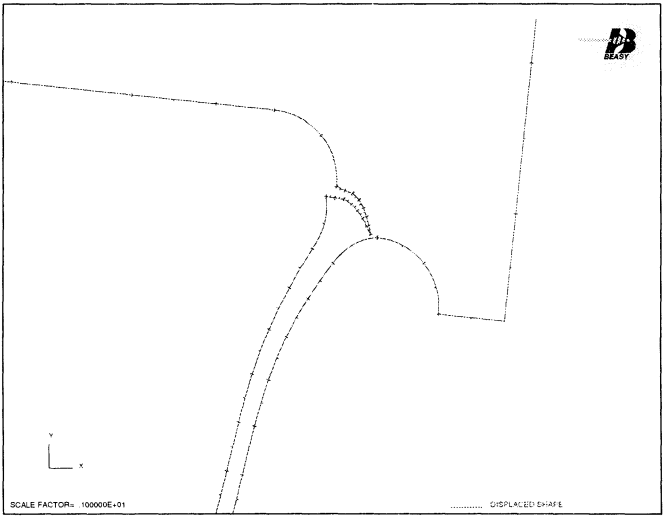


FIGURE 8. Prediction of how the crack will grow during fatigue loading.

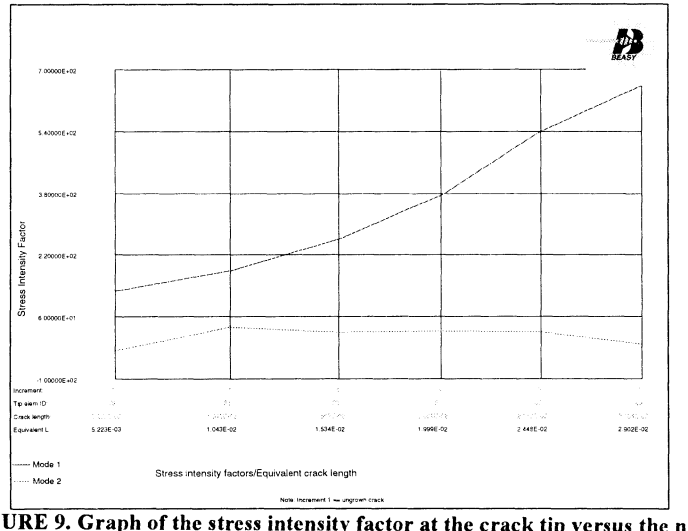


FIGURE 9. Graph of the stress intensity factor at the crack tip versus the number of loading cycles.

References

[1]Lessmollmann, C. Experimental results on the behaviour of micromechanical structure made by the LIGA technique. Proceedings International Conference on the Simulation and Design of Microsystems and Microstructures, Southampton UK 1995.

[2]BEASY. Computational Mechanics, Southampton, England.