

# APPLICATION OF FINITE ELEMENT METHODS TO SUGAR INDUSTRY EQUIPMENT

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## Abstract

A general overview of the use of the Finite Element Method (FEM) is given. It describes how FEM supplements industry design codes when dealing with non-standard shapes or complex loading conditions. It covers the reasons for the use of FEM, as well as a simple introduction to the underlying theory. Two examples are used to illustrate the application of the technique to sugar industry equipment, namely a continuous pan and a batch centrifugal basket.

## Introduction

### Why use Finite Element Methods?

Conventional design and analytical tools are often hard to apply to some of the equipment found in sugar factories; in some cases conventional tools are not applicable at all. Some examples where conventional techniques are inapplicable are:

- Calculating stress concentration factors (SCF) for sugar mill roll shafts and diffuser headshafts. Peterson (1974) published curves of SCF, however the  $r/d$  and  $d/D$  ratios (defined in Figure 1) for large sugar mill type shafts do not fall on the curves and hence the SCF is difficult to determine. Reid (1988) notes this and contracted the National Mechanical Engineering Research Institute to use FEM to establish the SCFs.
- Continuous pans have a shell shape which puts them outside the scope of the design codes conventionally used to design pressure vessels. The design code formulae are inapplicable in the case of continuous pans.
- Nozzles in the shells of evaporators. The diameter and thickness ratios and design pressures used for the design and construction of sugar factory evaporators are outside the scope of nozzle design sections of BS5500.
- Complex shaped mechanical components are not easy to analyse using conventional methods, for example the base plate and so-called spider of a batch centrifugal machine. The spider has a complex three-dimensional shape. Furthermore, the loading of the components of the basket is complex. FEM is almost essential to perform a proper analysis of the stress in such a piece of equipment.

In the above cases the choices are:

- be conservative and trust that the component or vessel won't fail catastrophically

- build full size prototypes and test and measure the stresses (with strain gauges, etc)
- use FEM.

The first mentioned choice is on one hand risky and on the other may make for unnecessarily expensive designs; the second is costly; however, the third is now relatively cheap and accessible.

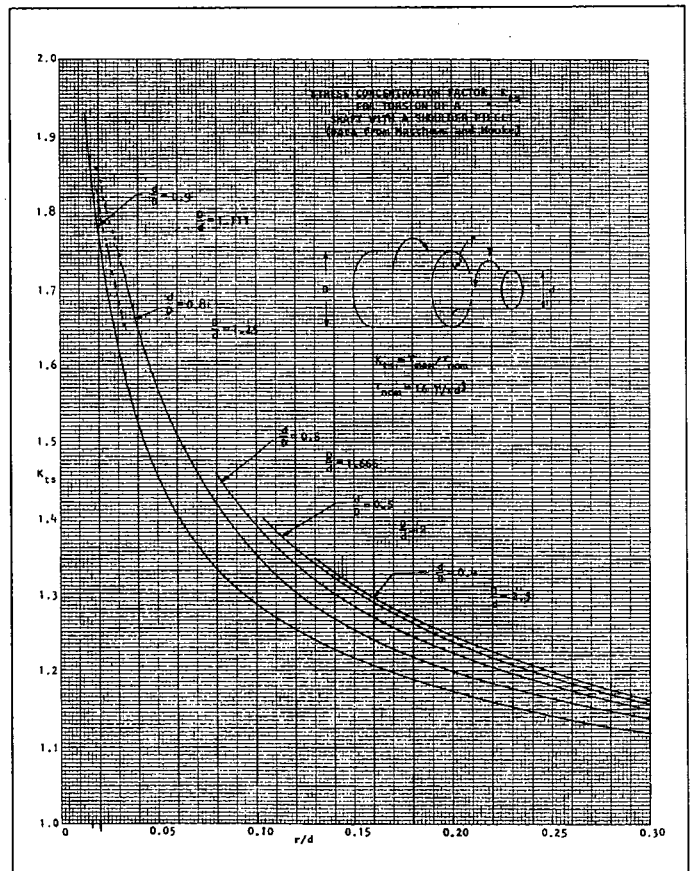


Figure 1. Stress concentration factor.

### Overview of FEM

The finite element method has been continually developed and improved since its inception in the 1950s. It was devised to overcome the difficulties in analysing structures having complex shapes, since force transmission paths in a continuum are not readily apparent.

The technique involves idealising a continuum by dividing it into a number of individual elements connected at nodal

points (see Figure 2). It represents the extension of matrix methods for skeletal structures to the analysis of continua.

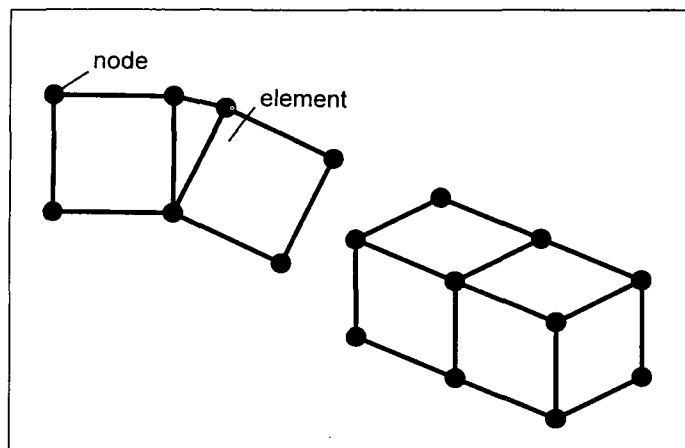


Figure 2. Surface and solid elements.

Basically, the finite element method involves the application of three conditions: equilibrium of forces between elements, compatibility of displacements (no element overlap during deformation) and element stress-strain relationships. It is possible to develop a picture of the stress distribution in the whole structure by analysing each of the finite elements in turn and then assembling the governing element equations to obtain the system equations.

The finite element method is now an extremely sophisticated tool capable of solving numerous engineering problems ranging from linear to nonlinear, thermal, fatigue and fluid flow. These problems can be steady state, eigenvalue (modal shapes and buckling) or transient (forced vibrations). Hence, due to its versatility, the technique can be applied to problems with complex geometrical properties and loading conditions.

The accuracy of the solution depends on the number of elements (subdivisions); the more there are the greater the accuracy. However, although the analysis of each element is straightforward, the analysis of a large number of elements becomes tedious. Hence the importance of the personal computer (PC), which is becoming increasingly attractive for finite element analysis. In fact, the growth of the technique is attributable to the rapid advance in computer technology and computing power. The increased capacities (processing speed, storage and memory), decrease in price and large number of available software packages make the PC well suited to the interactive development of the model (pre-processing) and interrogation of the results (post-processing). In addition, the software packages are designed to be robust and user-friendly.

Clearly, the potential areas of application are vast. The method is already widely used and accepted in many branches of industry including aerospace and automotive as well as in the sugar industry (Loughran *et al.*, 1995; Anderson and Loughran, 1996; Anderson *et al.*, 1997). Its development has not been paralleled by any other numerical analysis procedure.

## Discussion

The use of FEM in the sugar industry will be discussed by means of two examples: the first involves the design of a continuous vacuum pan, and the second the analysis of a batch centrifugal basket. The first shows how FEM is used for the initial design and analysis of new equipment. The second shows how FEM analysis was used to help in developing a repair procedure for a component that had corroded.

### Continuous vacuum pan

When designing any type of structure, uncertainty often arises when specifying the amount of material to be used (e.g. plate thickness). Even though excessive material might be used as a precaution (i.e. over-design), the areas exposed to the highest (perhaps critical) stresses are not readily apparent. Such was the case with the initial design of a 130 m<sup>3</sup> continuous pan. Loading conditions included internal vacuum and massecuite weight. Pressure vessel codes were not available for the complex shape.

After performing a linear static finite element analysis on the model, it became evident that much of the stiffening was unnecessary due to the predominantly low stresses. In addition, it was found that thinner plate would suffice in many areas. The amount of material could therefore be reduced, lowering the cost of manufacture.

The results of the analysis showed that the maximum stress occurred in an area adjacent to the outlet box (Figure 3). Hence it was decided to insert a stiffening brace here. Stresses as a result of differences in thermal growth were not evaluated because it is not a code requirement. However, it is believed that these stresses might be large enough to be important to the design, therefore work is continuing in order to assess the thermal stresses.

### Batch centrifugal basket

A number of 54-inch batch centrifugal baskets from FX had suffered corrosion to the non-stainless steel parts, namely the base plate, the 'spider', and the circumferential hoops. The shell of the basket and the top lip are made of stainless steel (Figure 4). The stainless steel components were not corroded, however fine cracks were evident on the top surface of the top lip. In order to assess the amount of damage and to plan what form the repairs should take an analysis of the basket was undertaken. The stresses in the shell and hoops could be established by means of thin cylinder theory, however simple theory could not be applied to the complex geometry of the base plate and spider. A solid FEM model of the whole basket, in the corroded condition, was created. A full model was created to ensure that the loading on the base plate and spider was accurate and realistic. The FEM analysis revealed the stress and deformation patterns shown in Figures 4 and 5. The highest stresses are at the largest radii, as expected. The stresses are all lower than those allowable for the various materials and loading cycles. Knowledge of the stresses in the components provided confidence to make informed decisions about the repair procedures. Without FEM it would be very difficult to be certain that the repair work would be safe.

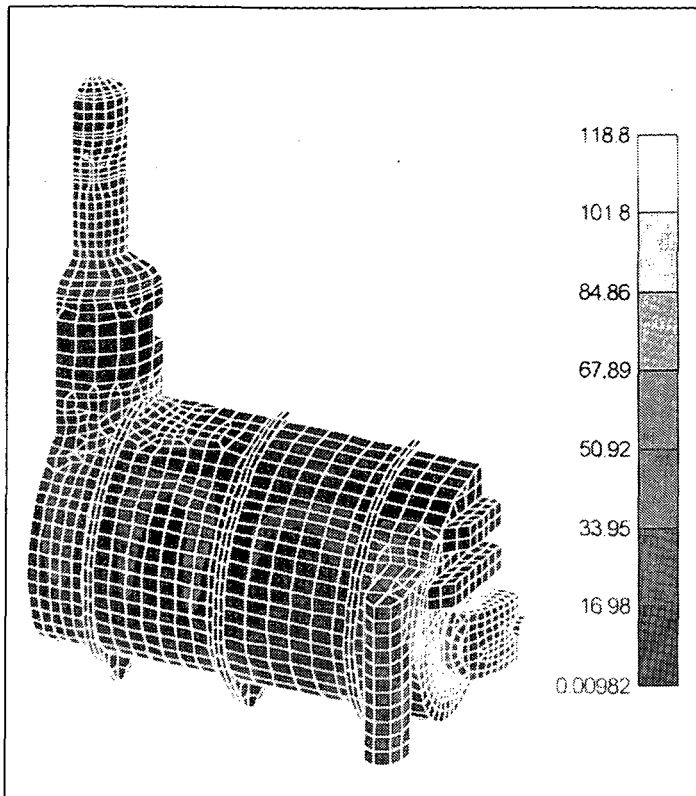


Figure 3. Quarter model of continuous vacuum pan showing von Mises stress in MPa.

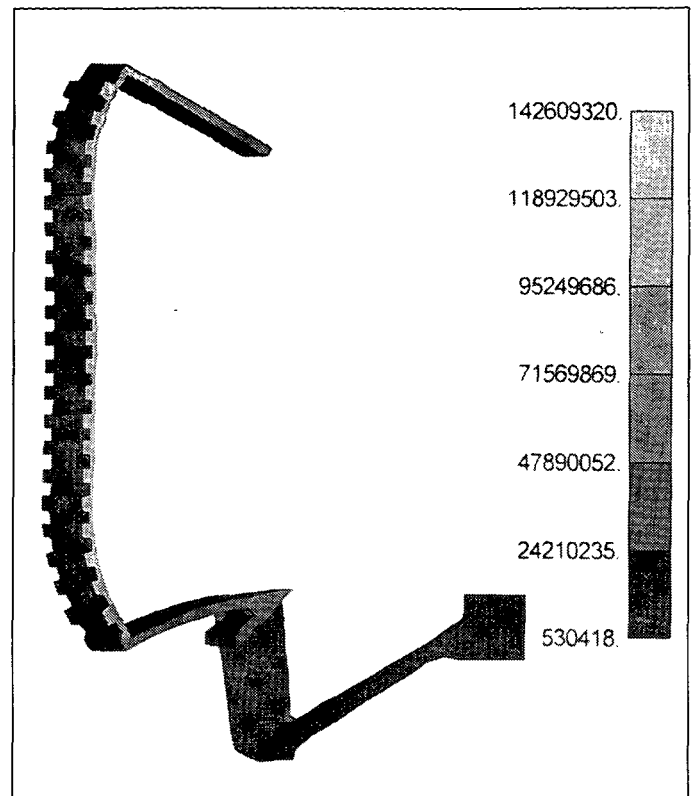


Figure 5. Segment of centrifugal basket showing exaggerated deformation and von Mises stresses in pascals under centrifugal loading.

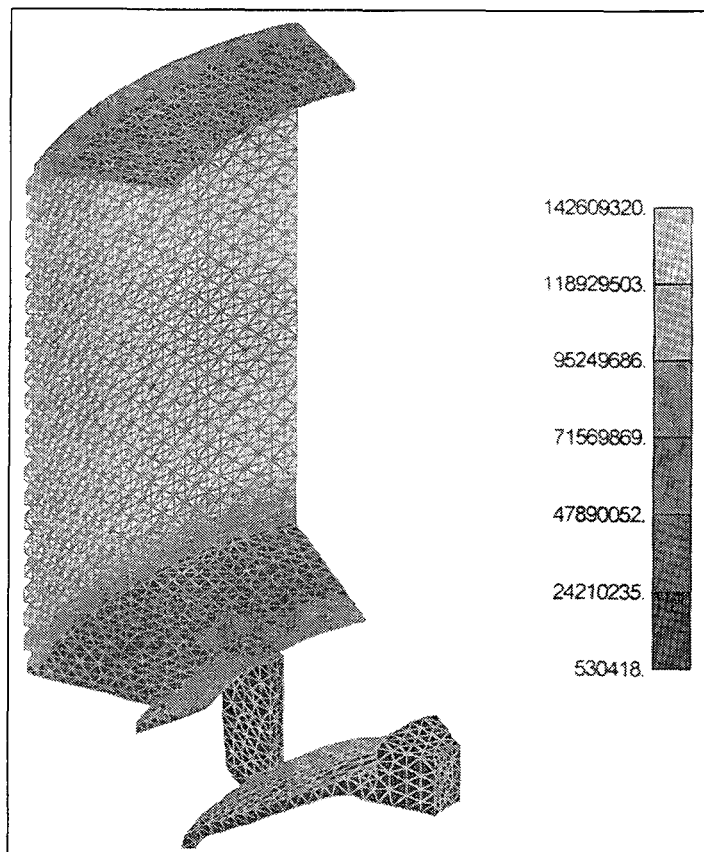


Figure 4. One-eighth section of centrifugal basket showing elements and von Mises stresses in pascals.

### Conclusions

The sugar industry has some unique components of plant and equipment, for example continuous vacuum pans that have large shell radii and operate under low pressures. The usual design codes were not written with these vessels in mind. Furthermore, the non-cylindrical shell shape makes it impossible to apply the code design formulae to the vessels. The use of FEM in the design of continuous vacuum pans helps ensure the pan complies with the pressure vessel codes without being so conservative that the vessel becomes too expensive. FEM can be used not only for design, but also to help extend the life of a component by giving confidence that repairs undertaken are safe and reliable, as in the case of the centrifugal basket discussed above.

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