

## REPORT ON 6-ELEMENT ROSETTE

### INTRODUCTION

The ASTM standard prescribes an acceptable eccentricity error margin of  $\pm 0.004D$  where  $D$  is the average gauge circle diameter (diameter of the circumference concentric with the rosette which passes through the centreline of the grids). Since  $D=5.1\text{mm}$  (for the most commonly used rosettes) the maximum eccentricity should not exceed 0.02mm. Such values can be obtained by using precision optical techniques for aligning the axis of the endmill with the centre of the rosette. Eccentricity values can sometimes be higher (in the region of 0.05mm); even such limited errors can have a significant effect (approx. 10%) on the evaluation of residual stresses based on hole-rosette concentricity.

Analytical correction of eccentricity is easily implementable by the numerical technique using Influence Functions but is not easy to achieve by the Integral Method with the calibration coefficients, as suggested by the ASTM standard. This study proposes using a 6-element rosette which allows systematic compensation of the effect of eccentricity. The actual compensation of the 6-element rosette is the subject of this study. In order to obtain experimental validation a flexure test bed was used on which it was possible to apply and remove a precisely known bending load thus simulating the presence of a residual bending stress, which has to be reproduced by the method. Successful reproduction of the simulated residual bending stress demonstrates the actual capacity of the 6-element rosette to compensate the eccentricity error.

### 6-ELEMENT ROSETTE

Fig. 1 shows an initial application of the 6-element rosette, which is the subject of this study. The configuration is similar to the conventional 3-element rosettes, with the difference that for each grid there is another diametrically opposed grid.

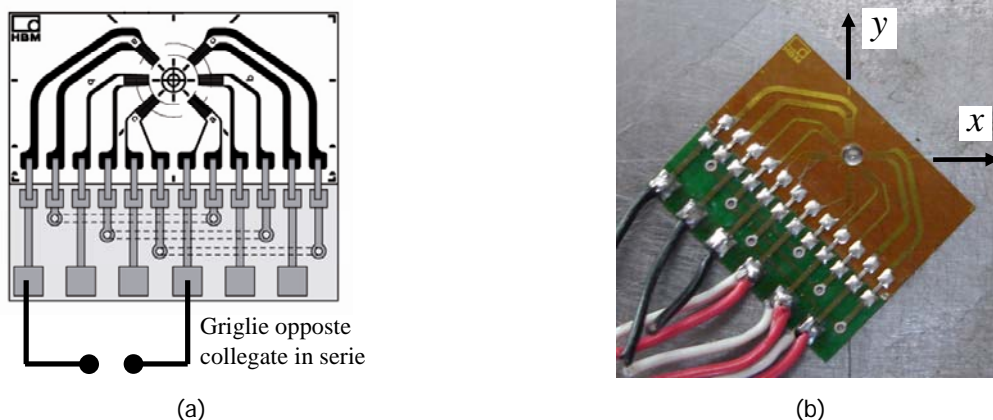


Figure 1 (a) 6-element rosette, opposed grids connected in series. (b) Wiring and drilling of an intentionally eccentric hole, hole diameter 1.8mm.

The 6-element rosette since is *self-compensating*, which is precisely what this study aims to verify. Each grid is connected in series with the opposed grid, Fig. 1(a). The total resistance of the grid is therefore the sum of the resistance of the two diametrically opposed grids, just as variation of the total resistance, due to strain, is the sum of the variations of the two opposite grids. The balancing effect is due to the fact that unless the hole is perfectly concentric, taking any one of the three measuring directions ( $0^\circ/45^\circ/90^\circ$ ), the grid closest to the hole measures a higher strain (in module) than it would have measured had the hole been concentric, whereas the diametrically opposed grid measures a lower strain. The variation in resistance is less on one grid but greater on the other, while the sum balances out, reproducing a measurement roughly equal to what would be obtained with a single grid if the hole were concentric. The 6-element rosette, therefore, connects with the acquisition system in precisely the same way as the standard 3-element rosette.

The 6-element rosette is perfectly balanced in the case of eccentricity having only an effect of the first order on the single strain gauge measurement. In such a case, an eccentricity perpendicular to the grid would produce a null variation whereas an eccentricity parallel to the grid would produce a variation in line with the component of eccentricity in that direction. The 6-element rosettes used in this study have an average diameter of 5.1 mm and are suitable for 1.8 mm endmills, Fig. 1(b).

### FLEXURE TEST BED AND VALIDATION PROCEDURE

A critical element in measurement by the hole-drilling method is the difficult repeatability and verification of the measurement. A recent proposal has been to use a flexure test bed that produces a stress distribution which is controlled and known with high precision both to measure the residual stress profile and at the same time to validate the measurement. The flexure test bed produces a monoaxial stress condition, with a low gradient (compared to the reduced hole depth in relation to the thickness of the specimen), known with high precision, because the force applied to the end can be measured and the stress therefore deduced by the simple beam flexure equation. The flexure test bed layout is shown in Fig. 2.

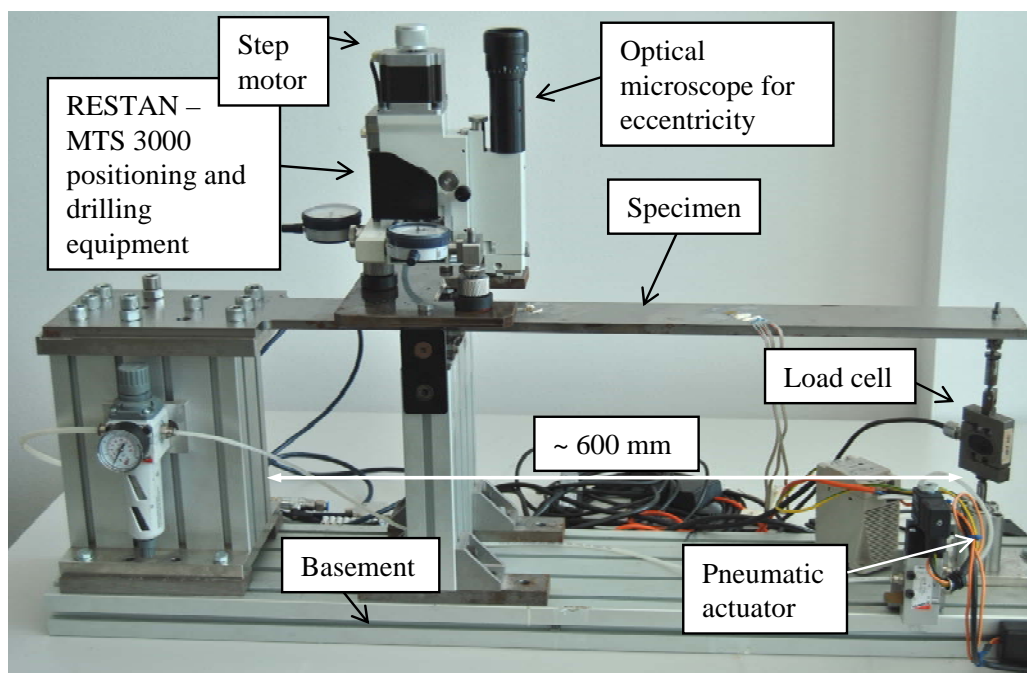


Fig. 2 Test bed for simulating a precision-known, residual bending stress.

### TESTS WITH 6-ELEMENT ROSETTES

Two tests were performed with 6-element rosettes. One test with virtually nil eccentricity and one test with very high eccentricity. Fig. 3 shows the comparison between expected relaxed strains and the relaxed strain values that emerged from the test for the 6-element rosette and the case of very low eccentricity:  $e_x=0.03\text{mm}$ .  $e_y=-0.025\text{mm}$ .

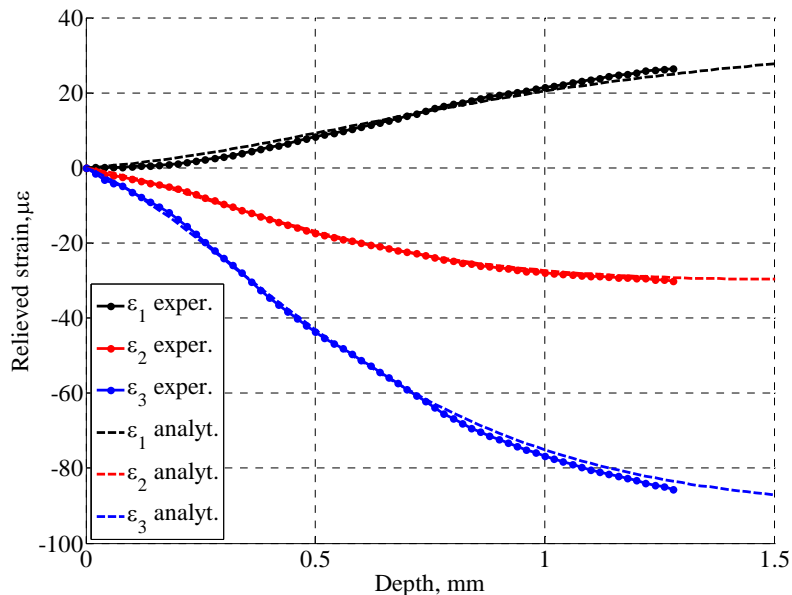


Figure 3. Expected relaxed strain values versus test values, with the 6-element rosette, negligible eccentricity.

The comparison for the 6-element rosette with high eccentricity components:  $e_x=0.23\text{mm}$ .  $e_y=-0.295\text{mm}$ . is shown in Fig. 4. The eccentricity of this second test with the 6-element rosette was determined intentionally and resulted approximately one order of magnitude greater than the previous one with 6 elements. The expected relaxed strains were calculated without introducing the eccentricity into the analytical procedure, in spite of the high eccentricity in the test. As can be seen, the compensation is very effective as the residual error is of the same order of magnitude as the error in the case of non-eccentricity, attributable to some other secondary effects, such as the inevitable geometric error of the hole.

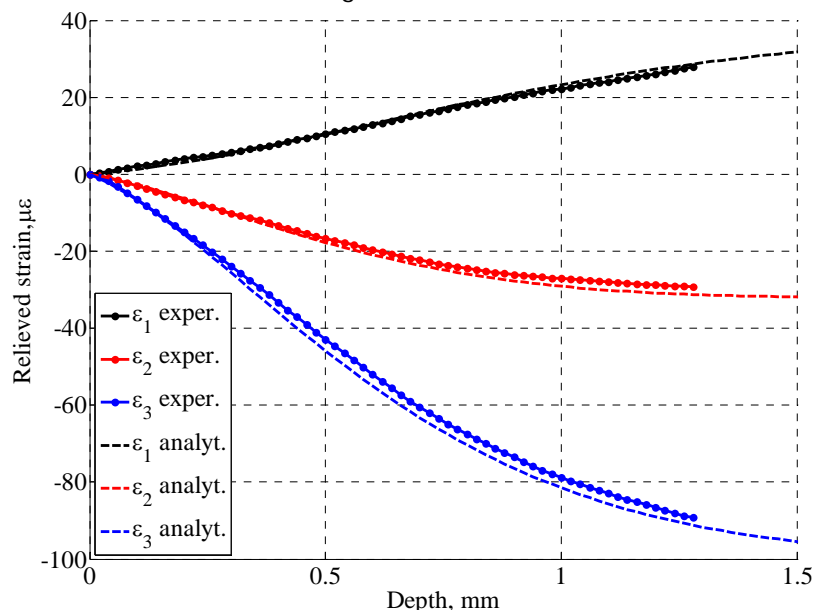


Figure 4. Expected relaxed strain values versus test values, with the 6-element rosette, high eccentricity components. Evident compensation effect.

Fig. 5 shows the same test outcome, compared with the expected strains in the case of a 3-element rosette and a symmetrical one, and introducing eccentricity correction in the analytical calculation, in one case with  $e_x=0.23\text{mm}$ ,  $e_y=-0.295\text{mm}$ , in the other with  $e_x=-0.23\text{mm}$ ,  $e_y=0.295\text{mm}$ . In this way, we simulate the response of two 3-element, independent, specularly-positioned rosettes, on which eccentricity has the opposite effect. The 6-element rosette gives the average of the two responses, interpreting very well the response there should be if eccentricity were nil. However, it is to be noted that expected relaxed strains are not the exact average of the relaxed strains measured by the specular rosettes, although the test result is. Indeed the compensation of the 6-element rosette is not total, but nevertheless very effective as can be seen from figures 4 and 5.

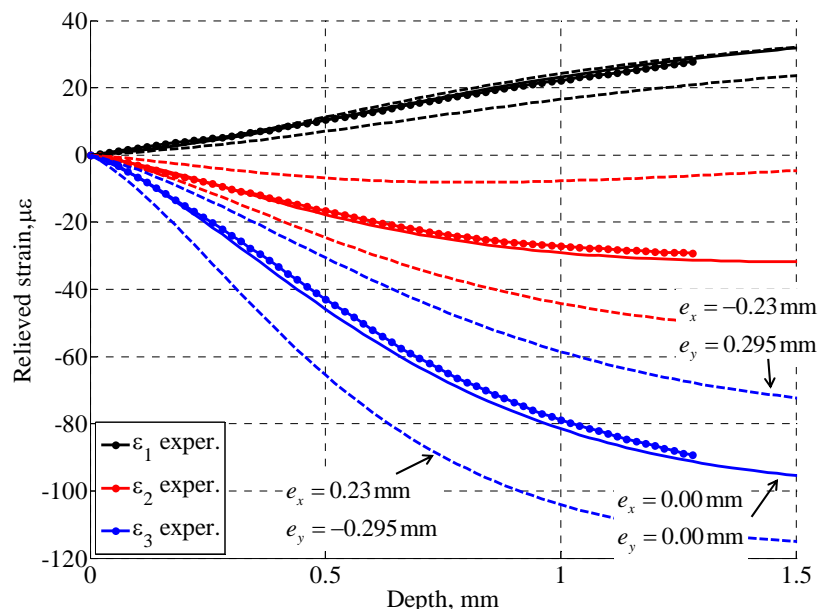


Figure 5. Expected relaxed strain values versus test values, with the 6-element rosette, high eccentricity. Analytical relaxed strains determined by simulating the readings of two 3-element, independent, specular rosettes. Evident compensation effect.

## CONCLUSIONS

1. The hole-rosette eccentricity error can imply non-negligible errors in terms of relaxed strains in relation to expected strains, particularly if the eccentricity values are greater than 0.02mm.
2. The 3-element rosettes have shown a considerable error due to eccentricity, but which can nevertheless be corrected should it be possible to measure the eccentricity and use a calculation technique to reconstruct the residual stresses that allows eccentricity to be considered as a geometric parameter.
3. The 6-element rosette offers the ability to *automatically* compensate the effect of eccentricity. For each element there are two diametrically opposed grids. When an eccentric hole has been drilled, the furthest grid reads a lower relaxed strain (in module) whereas the nearest grid reads a higher relaxed strain (in module). Since the two grids are connected in series, an average relaxed strain is obtained.
4. The proposed test bed has made it possible to simulate a precision-known residual bending stress. The relaxed strains read by the 6-element rosette were very similar to the expected strains, calculated from the reference stress distribution and considering nil eccentricity. It has therefore been experimentally verified that the 6-element rosette is capable of automatically compensating an eccentricity error of up to 0.2 – 0.3mm, much greater than the typical eccentricity.