Finite Element Based Analysis of the Effect Of Internal Voids on the Strength And Stress Distribution of Component

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ABSTRACT

Voids are basically casting defects and they can be source of failure due to effects like stress concentration location etc. Void is the absence of material where it should be present in the particular location. All metal casting contains voids which is inherent to the material and its application. Voids occur for many reasons and in many forms, but it is often the results of gases released from molten metal, or shrinkage of the metal as it cools and solidifies. Voids may go to the heart of casting and hence effect of particular void on the material properties such as deformation, stress, strain, loss in strength, natural frequency have to be determine. For determination of these properties finite element method can be used .The main objective of the project are to try and develop a model for detection of voids using vibration techniques. Once a void is detected, we should be able to quantify the loss in strength, and based on this data determine if the component will be usable or not .The analysis carried out using ANSYS workbench. By using FEA modeling of internal void in a component is determined and using modal analysis technique natural frequency of component is determined. The location of particular void has been changed from its original position in longitudinal and radial direction of the cylindrical component. By comparing results with defect free component it is checked that is there a co relation between frequency shift and size of the void. By performing structural FEA stress concentration zones and reduction in stress capacity due to void is determined.

Keywords – Deformation , Loss in strength , Modal analysis, Natural frequency, Stress concentration

I. INTRODUCTION

Typically certain casting processes are known to generate internal voids due to either air entrapment or due to inefficient cooling during the casting process. These voids affect the structural integrity of the component, and are typically not visible to the naked eye. If the component is critical, then it necessitates an X ray or Tomography test, under which detection of void leads to automatic rejection of the component. However if the component is not critical then such tests are not done, it leads to assembly of the component at a risk of failure. A number of methods have been developed to inspect castings for defects that may occur during their production. Such inspections may be in process inspections or finished product inspections. In process inspections are carried out before a lot of castings have been completed to detect any flaws that may have occurred in the process so that corrective measures can be taken to remove the defect in the remaining units. Finished product inspections are carried out after the castings have all been completed to make sure that the product meets the requirements specified by the customer. Void detection testing's are basically divided into destructive and non destructive testing.

II. FOCUS OF STUDY

Though the concept is not new, its practical applicability on variety of components and cost, accuracy and time involved are important aspects, which need to be taken into consideration. There were two pronged approaches. First scenario is that, void is present and is not detected and employed into use, then the FEA should establish as to what degree the strength has reduced and conditions that might entice failure. The second scenario is that, it is widely theorized that presence of a void may alter the vibration characteristics of a component. FEA would try to verify if this is true and then try to quantify the variation if possible.

The study is concentrated on spherical void in a cylindrical component, while the void size and location of void in component are being the variables. The analysis is done using ANSYS software and the output results summarized are induced equivalent stresses (von Mises Stress), plastic strain, natural frequency and harmonic response (deformation).

The material used is cast iron (grade 30). It has density 7000Kg/ m^3 . modulus of elasticity 180GPa and poissons ratio 0.32. The results obtained are tabulated results are shown graphically.

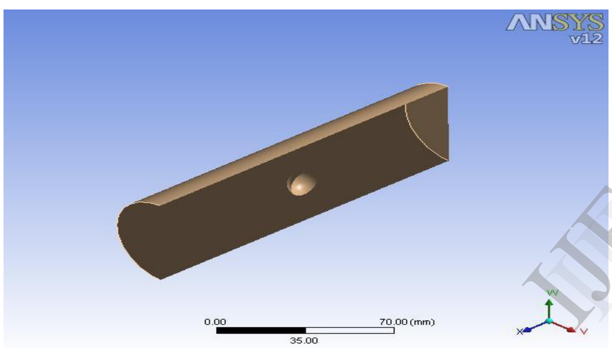

Fig. 1. Material Containing Internal void.

Typical model of material which has internal void is shown in figure. The material has length of 160mm and diameter of 50mm. the internal void size is varied from 1 micron to 15mm. during analysis the location of void also changed after each analysis and it is shifted along the length and along the radius in transverse direction. The component is analyzed as a cantilever beam with one end fixed and axial force applied on the other end. Effect of weight is incorporated by applying acceleration of 9.81 m/s^2 in upward direction as shown in figure 2. The meshing is done in ASNYS workbench only. The element size is optimized to 3.5 mm for Structural Analysis. The 3rd level refinement is used around the void to increase the accuracy.

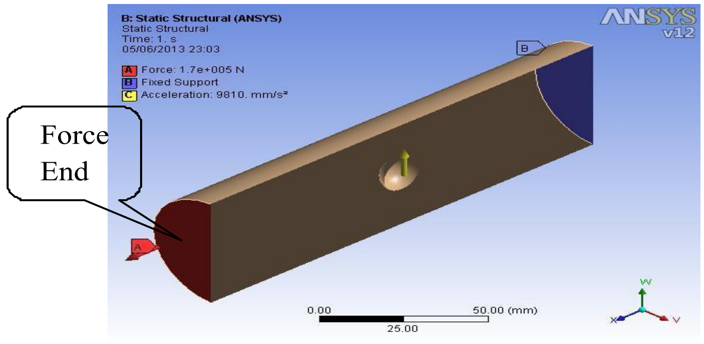

Fig.2Boundary conditions of material.

REASULTS

The structural analysis was carried out with material non-linearity for the forces above yield point. The size and location of void are varied and solutions of total deformation, equivalent stress (von Mises stress) and plastic strain found

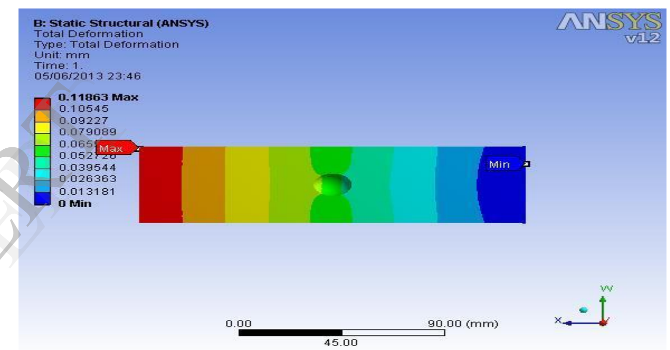

Fig.3 Showing Deformation of the Component having 10 mm Void

The results are verified by changing the void size from 1 micron to 15mm. The numerical results obtained are shown graphically.

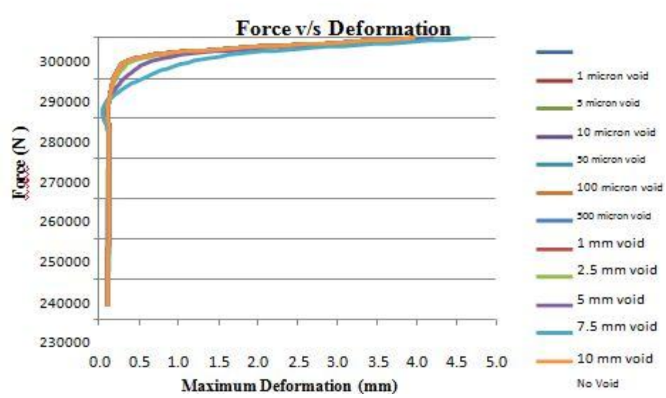

Fig. 4. Graph of force Vs Deformation

Graph it shows the effect of size of centrally located void on the deformation. From graph, it is seen that there is not much of effect of size on the maximum deformation of a component. The effect of size on deformation for very small voids i.e. up to 1 mm diameter is very small, as the lines in graph are overlapping. As diameter increases above 1 mm, the maximum deformation for a given force increases as the size of void increases. So for analyzing effect of location of void, the void size from 1 mm diameter are studied, approximating the effect of micron size void to 1 mm void.

The location of void also changed along the radial and longitudinal directions.

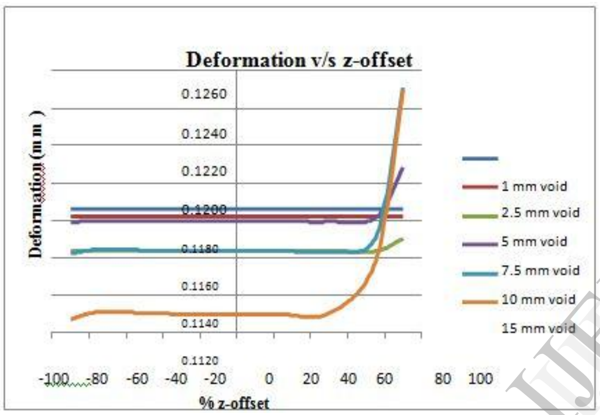

Fig 4. Showing Effect of Location of void (longitudinal direction) on Deformation.

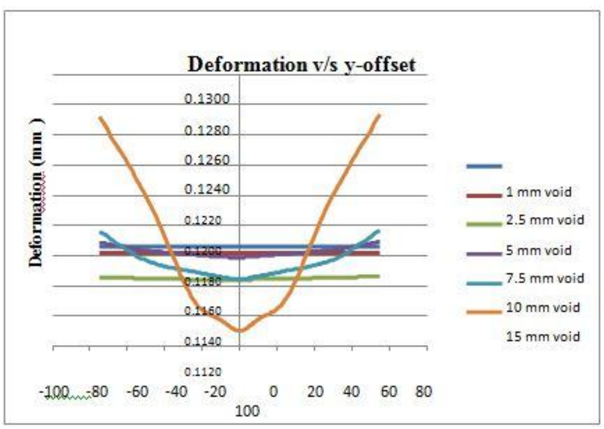

Fig .5. Showing Effect of Location of void (radial direction) on Deformation

Both the graphs show that the effect of shift is almost negligible. Though the larger void sizes show larger deformations towards the surface at force end and radial directions, the change is too small to get accounted. So the deformation is not that critical parameter to focus on, unless the void is larger and is just below the surface.

Effect of voids on Equivalent (von Mises) Stress also analyzed.

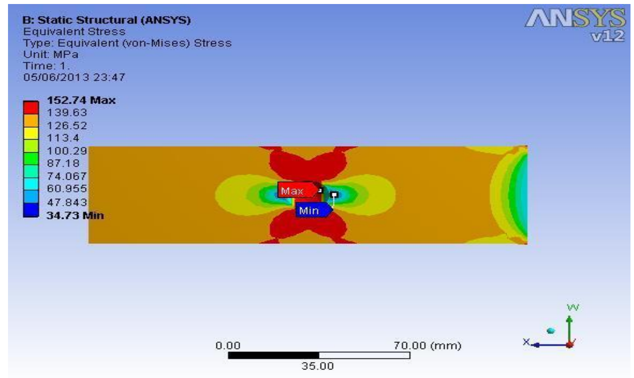

Fig 6. Showing Stress Distribution in a Component having 10 mm void.

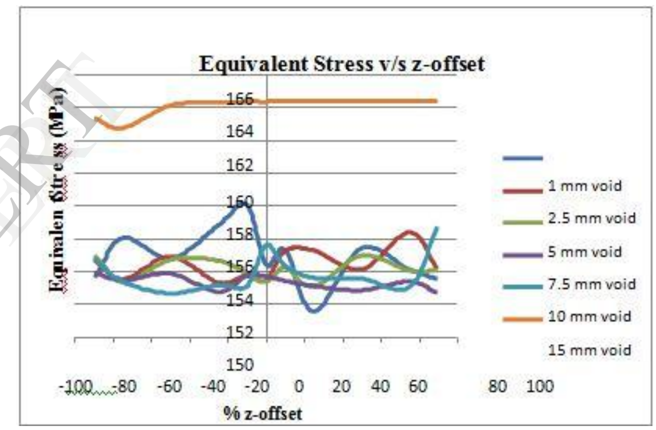

Fig 7. Showing Effect of Location of void (longitudinal direction) on Equivalent Stresses

The graphs show that the induced stresses are almost constant, while the void is shifted in longitudinal and radial directions. Also, the variation in stress is smaller for smaller voids and stresses increases promptly, as size of void increases furthermore. So, the size of the void is the factor, which needs to be considered in regards with induced stresses.

Figure 8 and 9 shows the plastic strain generated in component in a component. The location of plastic strain being at the void on the plane perpendicular to longitudinal direction, these locations have maximum possibility of generation of crack, which might entice failure.

Though analysis was done at the forces above yield point force, which might produce plastic strain, the location and the force at which plastic strain starts are important points to concern. Due to voids the plastic strain starts at much lower force than that commences plastic strain in defect free component.

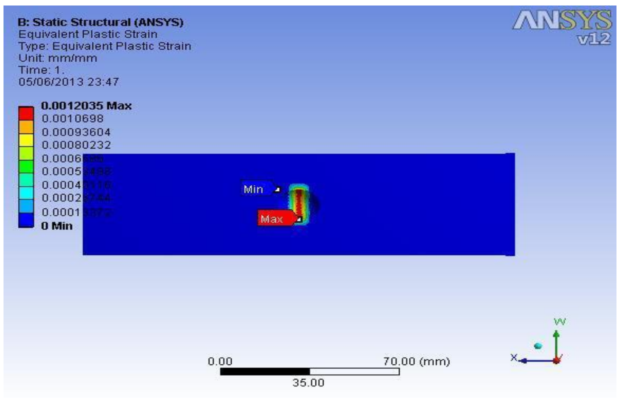

Fig. 8. Effect On Plastic Train

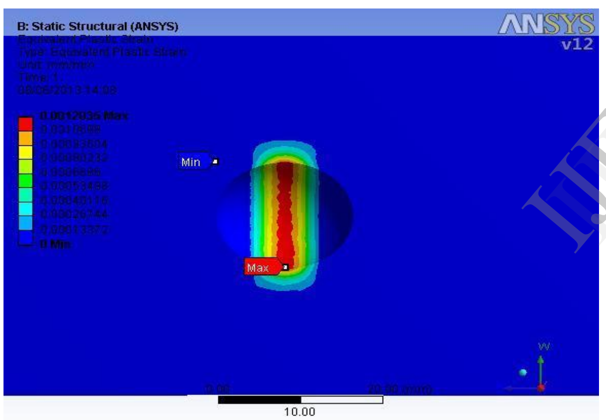

Fig. 9. Effect On Plastic Strain

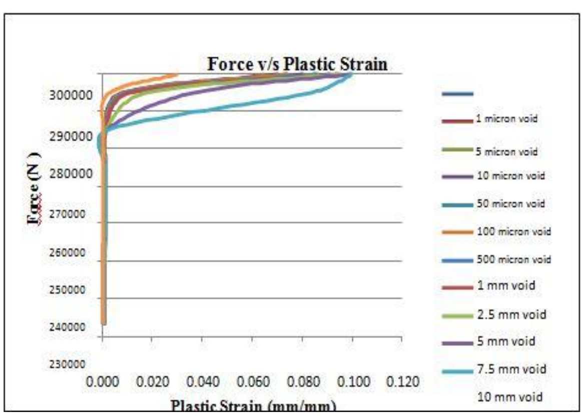

Fig. 10. Force Vs Plastic Strain.

Figure 10 shows that as size of void increases, the plastic strain increases. To compare effect of size of void, 1 micron of plastic strain was set as parameter. The force required to produce 1 micron of plastic strain also reduces as void size increases and this force is find out graphically. The force that produces 1 micron of plastic strain in the defected components is much smaller than that produces same amount of plastic strain in defect free component. Thus, we can conclude that the possibility of failure increases as the void size increases.

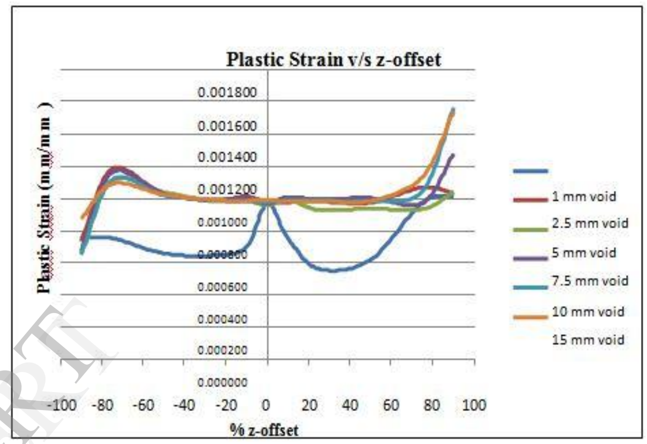

Fig. 11. Showing Effect of Location of void (longitudinal direction) on Plastic Strain.

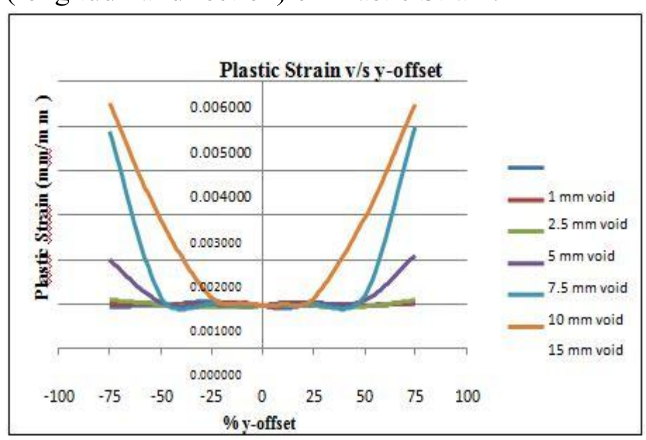

Fig 12. Showing Effect of Location of void (radial direction) on Plastic Strain.

The graphs from Figure 11 and 12, the trends in both the directions shows that, the effect on plastic strain is more in the direction of smaller dimension. Also, the sharp rise in effect towards the surface in radial direction shows that, shape of outer surface has some effect on development of plastic strain. The effect of offset in longitudinal direction is almost equal to that at center and stable, until the void approaches very close to the surface, where it shows sudden increase in plastic strain. Still it is very much less than that seen in radial direction, where the considerable effect is seen even after half way down and the effect too is much larger than that shown by the void at the center.

MODEL ANALYSIS

The modal analysis was done for both defect free and defected components, varying void size. The results of first mode shape were compared. The modal analysis of defect free component shows its natural frequency to be 1331.7Hz. When modal analysis was done for defected components, it is seen that, the Natural Frequency of a component changes due to presence of void and with increase in the size of the void, the shift in natural frequency increases.

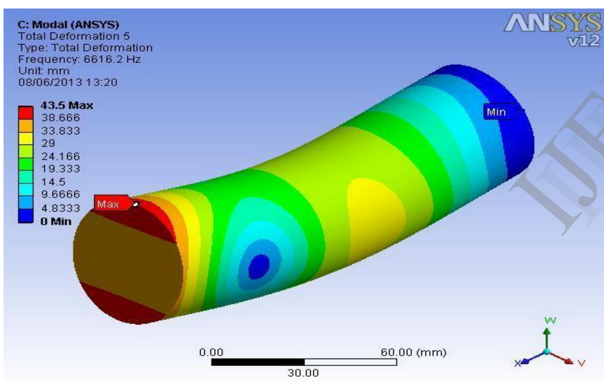

Fig. 13. Modal Analysis.

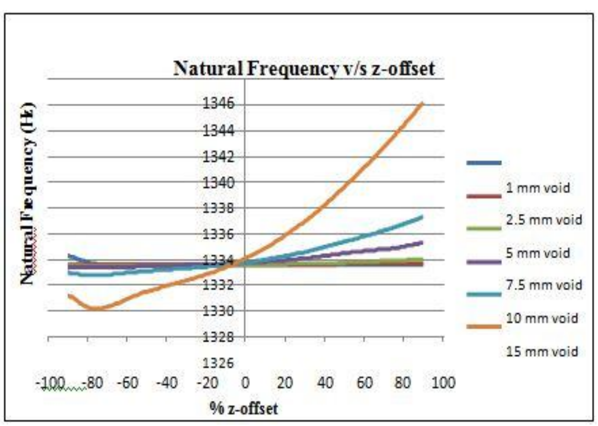

Fig.13. Showing the effect of location of void (longitudinal shift) on Natural Frequency.

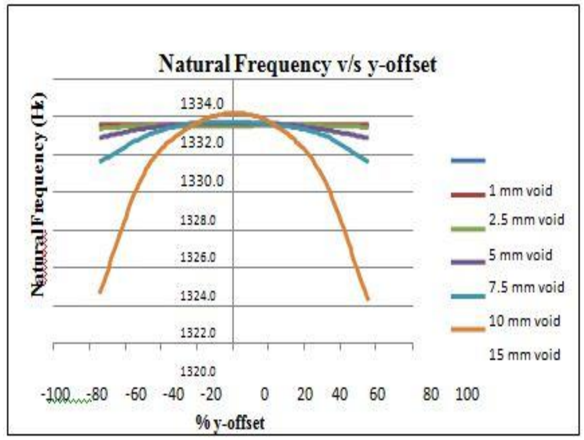

Fig. 14. Showing the effect of location of void (radial shift) on Natural Frequency.

Figure13 clearly indicates that with increase in size of the void, the natural frequency of a component shifts from that of defect free component, which was observed to be 1331.7 Hz. The effect observed for small voids is small, but as void size increases, it becomes more prominent and distinguishable. Moreover, the location of void has a bigger impact on the shift of natural frequency. Figures 13 and 14 show the effect of shift of void on the shift in natural frequency in longitudinal and radial directions respectively. Figure 14 shows that, as the void moves towards the fixed end, the natural frequency falls below 1331.7 Hz, while it increases as the void moves towards the force end. Figure 14 shows that, the effect of shift of void is symmetric in radial direction. As the void moves towards the surface in radial direction, the natural frequency drops below 1331.7 Hz.

HARMONIC ANALYSIS

The harmonic analysis was done for both defect free and defected components, varying void size. The harmonic analysis was carried out for natural frequency input of defect free component itself, i.e. at 1331.7 Hz, in the range of 1331-1332 Hz. When modal analysis was done for defected components, it is seen that, the harmonic response of a component shows quite a different values than that of defect free component.

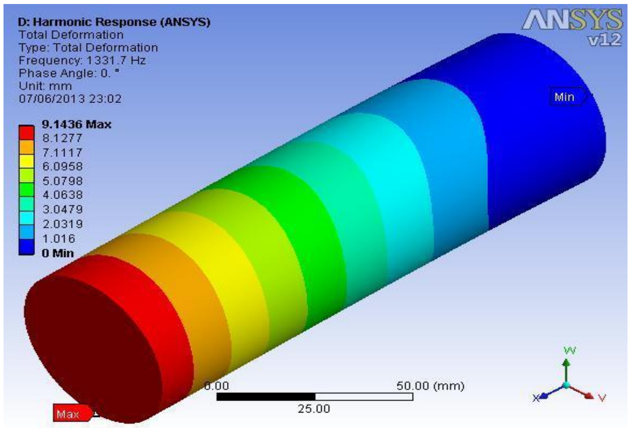

Fig 15. Harmonic Analysis

The harmonic deformations are summarized and the effects of void size and location are determined graphically below.

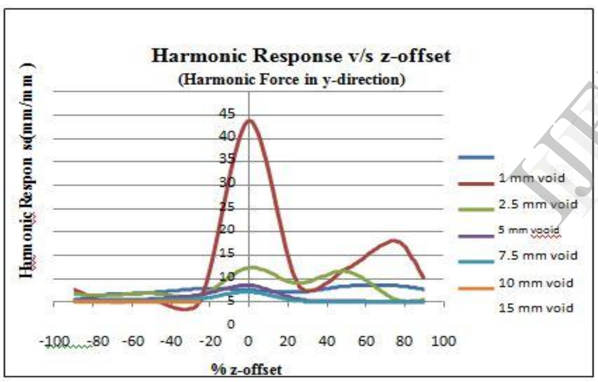

Fig 16. Showing the effect of location of void (longitudinal shift) on Harmonic Response with harmonic force in y-direction.

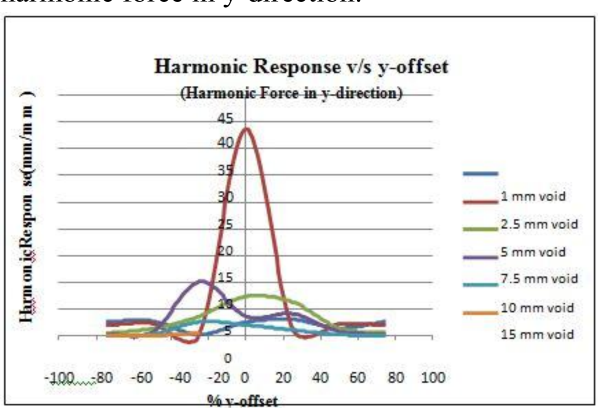

Fig 17. Showing the effect of location of void (radial shift) on Harmonic Response with harmonic force in y-direction.

Figures 16 and 17 shows the effect of void size and location on the harmonic response. Figure 16 shows that the slope of effect of void shift towards the fixed end is steeper than towards force end. Also, the harmonic response reduces rapidly with increase in void size. This is because of the shift of natural frequency of defected component. Figure 17 show the effect of shift in radial direction is almost symmetrical and the harmonic response reduces rapidly with increase in void size.

Conclusion

As the study shows, a component can be analyzed for the void of any size at any location and its effective loss of strength can be found out by integrating results of structural, modal and harmonic analysis and comparing experimental results of harmonic response. The study compares the observed vibration characteristics of defected component with the pre-produced database, which can directly tell about loss of strength. This methodology can be economically employed for components produced continuously/mass production, as the time taken is much less and data is to be produced only once. Prediction of effect of presence of void in terms of strength loss (loss in load taking capacity) can be used to decide to whether accept/reject the component, or to use it under reduced loads. The important points from the study are FEA can be used to determine the loss in strength in terms of loss of load taking capacity, due to presence of void. The loss in strength due to very small voids i.e. upto 1 mm can be directly approximated to that of 1 mm void. The effect of void is symmetrical in radial direction about central location, and as void moves towards surface, plastic strain and loss in strength increases. The effect of void is not symmetrical in longitudinal direction. The loss in strength increases as void moves towards force end, while it reduces as void moves towards fixed end from central location. The presence of void alters natural frequency of component. As the void size increases, natural frequency shifts to higher values. Effect of void in radial direction is symmetrical and natural frequency shifts to lower values, as void approaches closer to surface.

Future Scope

Still the issues of accuracy, cost effectiveness, time spent in producing data and its practical applicability over the variety products can be further studied to validate the methodology. Also, effects of shape of void, coexistence of multiple voids with random distribution can be studied and incorporated in future.

REFERENCES

Journal Papers:

1. “Porosity in Castings” R. Monroe, Steel Founders’ Society of America, Crystal Lake, Illinoi.
2. “Analyses of Void Growth and Coalescence in Cast Iron by Cell Models”, M. Kuna and D.-Z. Sun, Fraunhofer- Institute of Mechanics of Materials,Wohlerstrasse11, 79108 Freiburg, Germany.
3. “On ductile fracture initiation toughness: Effects of void volume fraction, void shape and void distribution”, Xiaosheng Gao, Tianhong Wang, Jinkook Kim, International Journal of Solids and Structures 42 (2005) 5097–5117.
4. “Effect of micro voids on stress triaxiality-plastic strain states of notched steels”, Zhiguang Zhoua, Hitoshi Kuwamurab, Akemi Nishidaa, Procedia Engineering 10 (2011) 1433–1439.
5. “Finite element analysis of void growth behaviour in nickel-based single crystal super alloys”, Q.M. Yu, N.X. Hou, Z.F. Yue, Computational Materials Science 48 (2010) 597–608.
6. “A constitutive description for casting aluminum alloy A104 based on the analysis of cylindrical and spherical void models” B. Chen, X. Peng, J. Fan, S. Chen; International Journal of Plasticity 21 (2005) 2232–2253.
7. “Casting defects and fatigue strength of a die cast aluminium alloy: a comparison between standard specimens and production components”, M. Avalle, G. Belingardi, M.P. Cavatorta , R. Doglione, International Journal of Fatigue 24 (2002) 1–9.
8. “Finite Element Analysis” by S. S. Bhavikatti, New Age International Publications.