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by Irsyadi Yani

Vibration analysis of rotary cement kiln using finite element method

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Abstract. . In this research, the implementation of shell of kiln problem has been discussed. The results are analysed in detail in this research for fatigue life for the shell of a kiln. In this work, the shell of the kiln has been modelled by Solid Works. This simulation showed how the most relevant aspects of the developed work presented in this paper can contribute to the state-of-the-art of the analysis of fatigue life of rotary cement kiln technique with innovative ideas and strategies. It also reviews that the obtained results achieve the proposed objectives. Based on the FEA the transfer matrices and overall transfer equation are developed to calculate natural frequencies, and response overall motion equation is established for response analysis. Due to the dimensionality of the problem addressed, the research specification has to set limits to the applicability of the research by selecting only mechanical load problems in rotary cement kiln tasks and goal-seeking to predict the fatigue life simulation investigated. From the simulation, model and boundary conditions are defined. Crack growth behaviour in the rotary kiln was predicted.

1 Introduction

A kiln is basically an industrial oven, and although the term is generic, several quite distinctive designs have been used over the years, such a kiln in PT. Semen Baturaja made about 1,200.000 tonnes of clinker per year. Rotary kiln shell is a large scale welded structure with 4.5 m in diameter and 75 m in length, and produced by welding thin cylindrical steel plate one by one.

Padded plates are directly soldered to the shell in the supporting rollers places to reduce their concentrated stress. Crack are often initiated at these welded joints, and the over long circumferential crack are prevailing at welded joints near the supporting rollers.

However, Kikuchi et.al, (2010) has predicted of two interacting surface cracks of dissimilar sizes by FEA. The simulations were performed for fatigue crack growth experiments and the method validity was shown on this research. It was shown that the offset distance and the relative size were both important parameters to determine the interaction between two surfaces of crack; the smaller crack stopped growing when the difference in size was large. It was possible to judge whether the effect of interaction should be based on the correlation between the relative spacing and relative size. In 2014, Fatigue crack growth simulation in heterogeneous material using finite element method has generated by Kikuchi et.al. Kikuchi have developed a fully automatic fatigue crack growth simulation system using FEM and applied it to three-dimensional surface crack problems, in order to evaluate the interaction of multiple surface cracks, and the crack closure effects of surface cracks. The system is modified to manage residual stress field problems, and the stress corrosion cracking process is simulated.

The prediction of crack propagation under thermal, residual stress fields using S-Version FEM (S-FEM), Kikuchi was employed to solve a crack growth problem by combining with the auto-meshing technique, this re-meshing process of the local mesh becomes very simple, and modelling of three-dimensional crack shape becomes computationally easy. On the other hand, in 2004, Irsyadi has developed visualization of finite element analysis in 3D (C, C++, under Linux/Fedora), with this system, analysis for extra-large problems such as fatigue life predictions becomes easy and fastly. Irsyadi, Kikuchi, and Kanto employed numerical analysis of 3-D Surface Crack in 2006, and then, Irsyadi and Kikuchi was developed a numerical analysis in the low carbon steel by finite element method and experimental method under fatigue loading. In this research they were predicted fatigue life of material under stresses.

The prediction of fatigue life of rotary cement kiln welded shell is not completely understood, therefore it should be investigated. For rotary kiln shell where the vibration occurs with high displacement, cracks can grow with a complex overloading conditions for over thousands of tons, and then results in premature shell failure. The affecting conditions crack growth include material characteristics, initial crack size, service stresses, and stress concentration due to overheated in hot spot area, all these conditions are random. The fatigue life of the welded shell during crack growth need to be predicted numerically by using finite element analysis and experimentally. In relation to the problems

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above, we propose the research topic of vibration analysis and fatigue life analysis of rotary cement kiln (case study in PT. Semen Baturaja).

The primary objective of this study is to investigate the area of vibration with high displacement and fatigue life of the crack growth analysis in a rotary cement kiln in PT. Semen Baturaja.

2 Research method

This research has the overall goal of identifying the characteristics of crack growth that determine fatigue life and hence the risk posed to rotary cement kiln (welded shell). To accomplish this goal, this collaboration research brings together a multi-disciplinary team with expertise in Tribology, Fracture Mechanics, Computational Mechanics and Smart Engineering. It includes two research projects: 1). Dynamic modelling and analysis of the large-scale rotary machine with multi supporting; and 2). Fatigue life of rotary kiln, along with supporting cores.

Separate report follow for each of the projects. In each section, we discuss: a). the research performed and results generated in this year, and b). the challenges encountered in the research and proposed actions.

Research Project 1: Dynamic modelling and analysis of the large-scale rotary machine with multi supporting.

The analysis of dynamic modelling of the kiln shell is shown in Figure 1 and Figure 2

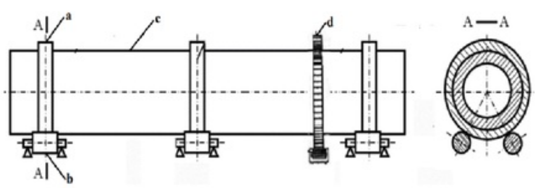
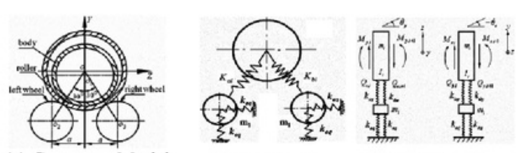


Fig. 1. The sketch of the large-scale rotary machine with multi-supporting. (a: tyre, b: roller, c: body, d: kiln drive)



(a) Geometry Model (b) Mechanic model (c) The Sketch in y and z plane

Fig. 2. The geometry and mechanic model of wheel bearing supporting structure

Data Input:
Mass of rotary kiln shell = 55.92 ton.
The weight of rotary kiln shell = 54,86 x 104 N

The data of mass, material the rotary kiln and the boundary conditions are shown in Figure 3, Table 1 and Figure 4 respectively.

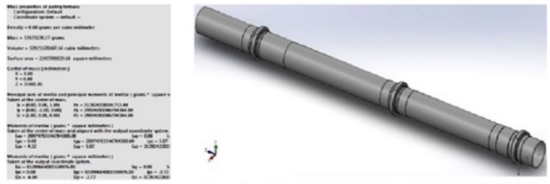


Fig. 3. Mass of rotary kiln shell is calculated by Autodesk 2016

Table 1. Material of a kiln shell

No	Specification of ASTM 516 Grade 70	Value
1.	Tensile strength	485 MPa
2.	Yield strength	260 MPa
3.	Density	7.85 gr/cm^3
4.	Poisson ratio	0.29
5.	Modulus of elasticity	200 GPa

Boundary Conditions:

- Type of analysis: Natural Frequency with (modal) load stiffening.
- Clinker weight is neglected.
- Speed of rotary kiln = 3.5 rpm.
- Ambient temperature = 37^{0}C.
- The kiln shell inclination (deviation) = 3.5^0
- Rotation Axis be based on the position of kiln drive

X = - 57149. 77 mm
Y = 29605.84 mm
Z = 27150. 75 mm

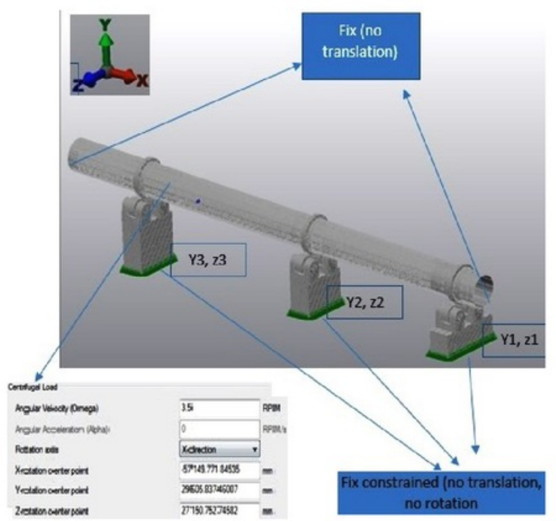


Fig. 4. Boundary condition

3 Results and discussion

We computed the natural frequencies of the body system of a rotary kiln, as well as the response with axis line deflection of the supporting structure. The rotary kiln is shown in Fig 1. The body length and radius are 75 m and 4.5 m respectively, the total weight is 54,86 x 10^4 N. The kiln has 3 supporting structures, located 4 m, 31 m, and 62 m from kiln head respectively. The kiln shell is divided into various elements according to body structure as shown in Figure 1 (b: roller). Any subsystem is composed of rigid disks, elastic shafts, and linear springs.

Anisotropy stiffness of the supporting structures in y and z directions are given as follows (see Figure. 5);

Direction	K Value
Y	K_{yy1} = 6.5 x 10^4 N/mm, K_{yy2} = 36 x 10^4 N/mm, K_{yy3} = 39.08 x 10^4 N/mm
Z	K_{zz1} = 3.76 x 10^4 N/mm, K_{zz2} = 20.78 x 10^4 N/mm, K_{zz3} = 20.56 x 10^4 N/mm

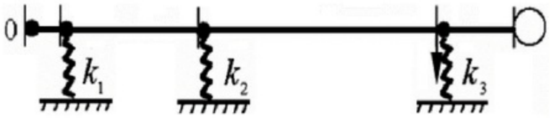


Fig. 5. The sketch of rotary kiln and dynamics model of the body system.

Table 2. Order of natural frequencies of a kiln shell. β_k (for k=1, 2, 3, ... 150)

Number of frequency	Circular frequency (rad/sec)	Frequency (Hertz)	Priode (sec)
1	1136600	180900	552,80
2	1157100	184160	543,01
3	1756500	279550	357,71
4	1785700	284200	351,86
5	1814300	288760	346,31
…	...	...	...
143	15188000	2417200	41,37
144	15284000	2432500	41,11
145	15429000	2455700	40,72
146	15453000	2459400	40,66
147	15566000	2477400	40,36
148	15642000	2489500	40,17
149	15673000	2494400	40,09
150	**15715000**	**2501100**	**39,98**

Natural frequencies of the rotary kiln.

The results of the natural frequencies β_k (k = 1, 2, 3, ... 150) of the body system are shown in Table 2. Displacement value at first of 150 number of frequencies are shown in Figure 6, Figure7 and Figure 8. It can be seen clearly from Table 2 that the results of natural frequencies obtained by FEM are shown in Figure 9.

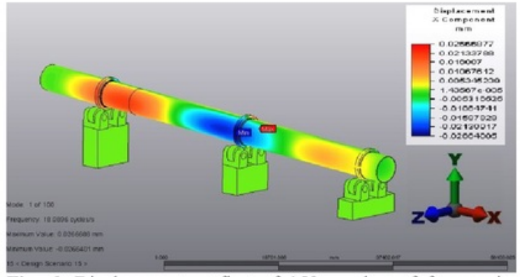


Fig. 6. Displacement at first of 150 number of frequencies along x-axis

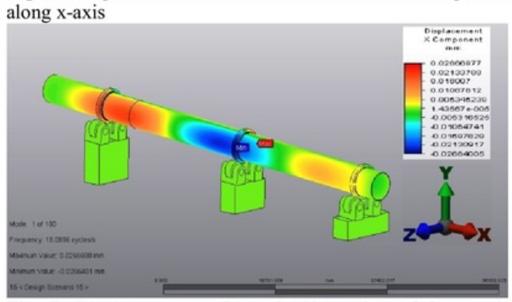


Fig. 7. Displacement at first of 150 number of frequencies along y-axis

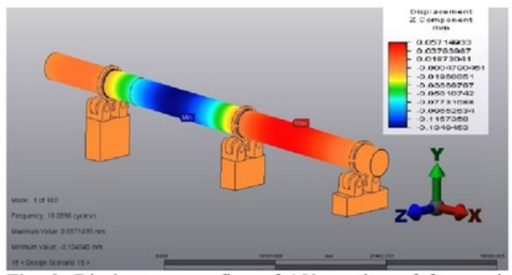
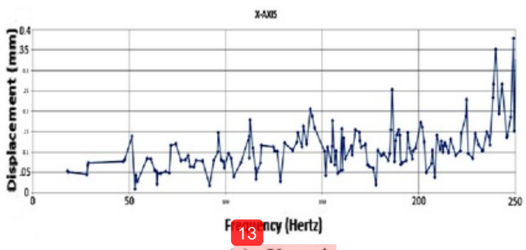


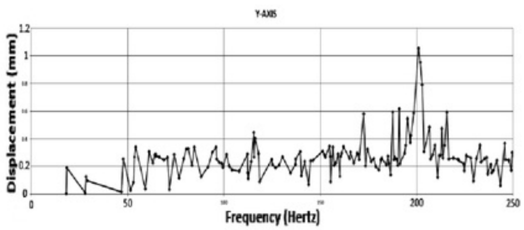
Fig. 8. Displacement at first of 150 number of frequencies along Z-axis

Research Project 2: Fatigue life of rotary kiln along with supporting cores.

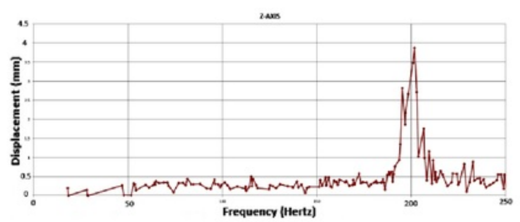
Considering a finite element analysis, characteristics of a kiln shell are a pretension and a mating part contact. The pretension can generally be modeled with static loading, thermal deformation, a constraint equation, or an initial strain. For a thermal deformation method, the pretension is generated by assigning virtual different temperatures and thermal expansion coefficients to the shell, clinker and temperature of gases. In this work, in order to generate a finite element model for the kiln shell with clinker and temperature of gases, two kinds of models are introduced. All the proposed models are taken into account above primary characteristics such as a pretension effect and a contact behavior between shell, clinker and temperature of gases. The prediction of the crack propagation are considered on crack emanating from contact surface between kiln shell and clinker and welded joint on the kiln shell surface. On this finite element model, the final mesh consisted of 40,856 elements and 45,245 nodes. Based on vibration analysis and thermal analysis, the elements along the direction of crack advance had a length of 13-23 m and 22-24 m respectively. Following the stress and deformation simulation, fatigue crack growth was modelled by repeated loading (mass of clinker and thermal gases), unloading, advancing the crack and then the loading again.



(a) X - axis



(b) Y - axis



(c) Z - axis

Fig. 9. The results of natural frequencies by FEM

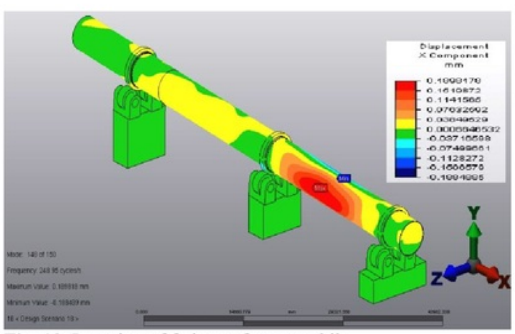


Fig. 10. Location of fatigue of a rotary kiln

4 Conclusion

The dynamics of the large scale rotary machine with multiple wheel bearing structures is investigated in this research. Based on the finite element method, the transfer matrices and overall transfer equation are developed to calculate natural frequencies, and response overall motion equation is established for response analysis.

Structures are simplified as linear springs, and their anisotropy equivalent stiffness are deduced. Taken a rotary kiln as an instance, natural frequencies, modal curves, and response vibration are obtained. The body vibration modal curves illustrate the cause of dynamical errors in common axis line measurement methods. The displacement response can be used for further measurement dynamical error analysis and compensation. The response overall motion equation could be applied to predict the body motion under abnormal mechanics condition, and provide theory guidance for machine failure diagnosis.

The main goal of the work presented in this research is to propose fatigue life analysis algorithm in the shell of a kiln using finite element analysis. Due to the dimensionality of the problem addressed, the research specification has to set limits to the applicability of the research by selecting only mechanical load problems in rotary cement kiln tasks and goal-seeking, to predict the fatigue life simulation investigated.
From the simulation, model and boundary conditions are defined. Crack growth behavior in rotary kiln was predicted. As the crack grows, the speed of the crack depth increase.

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