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An Experiment Method for Determining Natural Frequency of Complex Shape in Casting Process

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Abstract

This study is to present a method to determine the main natural frequency of aluminium casting and sand core from aluminium casting process. The method is known as bump test. It uses accelerometer with charge amplifier to collect the vibration data and uses spectrum analyzer to display the vibration signal. Analysis is carried out with LabVIEW software to find the natural frequency of aluminium casting and sand core by FFT technique.

1. Introduction

Casting process is a useful shaping technique that allows molten metal to solidify in a mould with a prepared core. In general, to produce a casting with an internal cavity, a core made of bonded sand has to be made to form a sold form. Then, this core is placed into the mould and molten metal poured around the core. After the metal has cooled, the core has to be removed from the casting. There are two different kinds of cores; i.e., shell core and solid core. This study concentrates on only shell core. Figures 1 and 2 show typical shapes of aluminium casting and shell core.

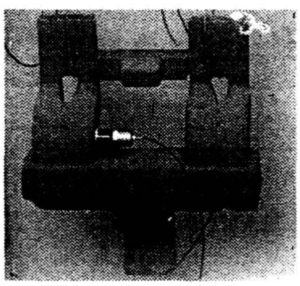


Fig. 1 The body of shell core

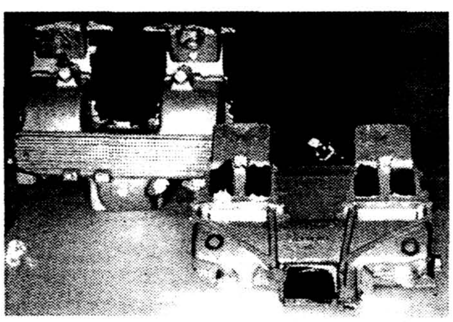


Fig. 2 The body of aluminium casting

During the casting process, the heat from the metal will dissipate into mould wall, shell core and its binder. This heat burns a certain amount of binder away, but unfortunately not all. The remainder of shell core has to be removed by a knock out process as shown in Fig. 3. The casting is clamped between two metal heads and pneumatic hammer vibrates to loose up the remaining shell core until it drops out completely. Although the pneumatic hammering machine can dislodge the remaining shell core, it is very noisy and inefficient. Actually, a shell core should be loosen from casting at a certain frequency. When material is acted upon close to its natural frequency, it can vibrate with a very large amplitude. Therefore, shell core should drop out efficiently and quickly. In this study, experiment is used to determine the main natural frequency of bodies. Bump test is the method used in this study [1-4]. Data are collected in time domain by using accelerometer and FFT (Fast Fourier Transform) technique is used to analyze the result in frequency domain [5-11].

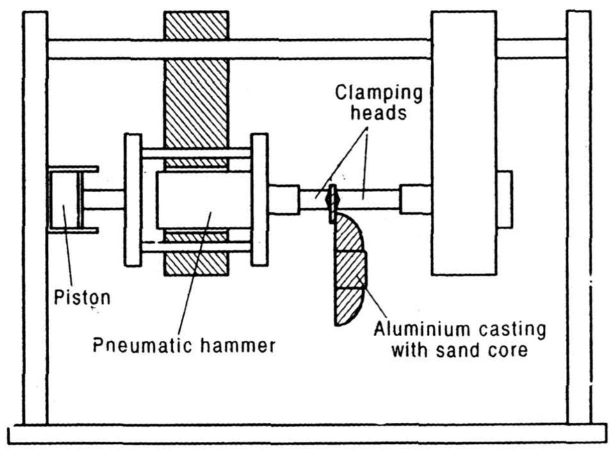


Fig. 3 Pneumatic-hammering machine

2. Theory

It is well known that a continuous body can usually be modelled as a multiple degree of freedom spring-mass system in a vibration analysis [4]. For example, the transverse vibration of a beam can be approximated by a n-degrees of freedom spring-mass system as shown in Fig. 4. The differential equations can be written in the form

$$[M][\ddot{x}]+[K][x]=[F] \tag{1}$$

where $[M]$ and $[K]$ are symmetric $n \times n$ mass and stiffness matrices, respectively, $[x]$ is a $n \times 1$ column vector of generalized coordinates and $[F]$ is a $n \times 1$ column vector of external force.

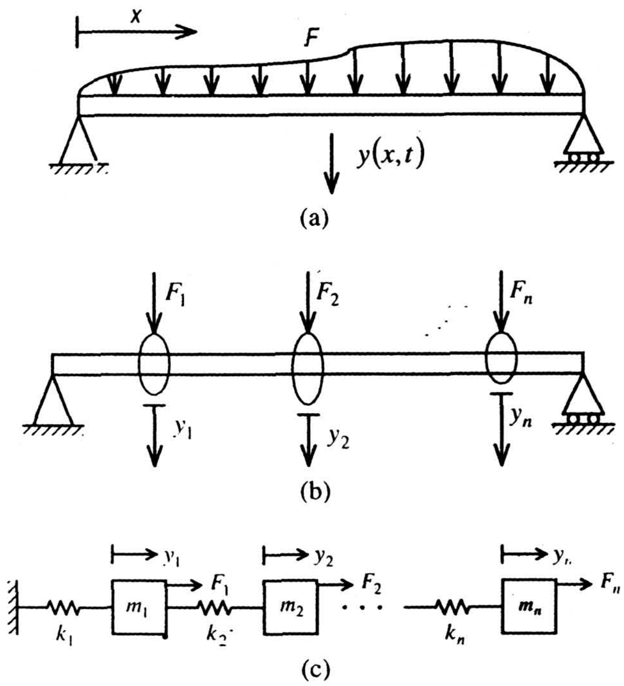


Figure 4 (a) Transverse vibration of a beam is described by $y(x,t)$. (b) A discrete model with $y_1, y_2, \ldots, y_n$ as generalized coordinates. (c) Analogous spring-mass system.

In the absence of external force, i.e., free vibration, (1) admits n independent solutions with n natural frequencies and n independent associate mode shapes. Any free vibration motion will be a linear combination of all mode shapes. If the external force $[F]$ is harmonic or periodic with its frequency equal to a natural frequency, resonance occurs. In practice, this means the amplitude of vibration $[x]$ can be very large even though the magnitude of the input $[F]$ is not.

On the other hand, if the beam is regarded as a continuous body, the equation for the transverse motion of the beam is given by

$$\frac{\partial^2}{\partial x^2}\left(EI\frac{\partial^2 y}{\partial x^2}\right)+\rho\frac{\partial^2 y}{\partial t^2}=F(x,t) \tag{2}$$

The free vibration solution of (2), i.e., with $F(x,t)=0$, has infinite natural frequencies with infinite number of associated mode shapes. Again, if the external force $F(x,t)$ is harmonic or periodic in the time domain, resonance can occur when the frequency of $F(x,t)$ is equal or close to a natural frequency of the system.

For a body with more complex shape, a set of equations for the motion of an elastic body must be used, i.e.,

$$\rho\,\ddot{\boldsymbol{x}}=\nabla\cdot\boldsymbol{T}+\rho\,\boldsymbol{b} \tag{3}$$

where $\boldsymbol{x}$ is the position vector, $\ddot{\boldsymbol{x}}$ the acceleration vector, ρ the mass density, $\boldsymbol{T}$ the stress tensor and $\boldsymbol{b}$ the body force. The stress tensor $\boldsymbol{T}$ is related to the motion through the constitutive equations for a linear elastic material. The equation (3) must then be solved subjected to appropriate boundary conditions, e.g., applied traction on the surface of the body.

In the absence of applied traction, the body will undergo free vibration with infinite natural frequencies and infinite mode shapes. A vibrating motion mainly in one direction will have the fundamental or lowest natural frequency different from motion in another direction. Again, a resonant phenomenon can occur when an external force is applied at a frequency close to or equal to a natural one.

Although it is extremely difficult to determine mathematically the natural frequencies of a complex body, experimental methods can be used.

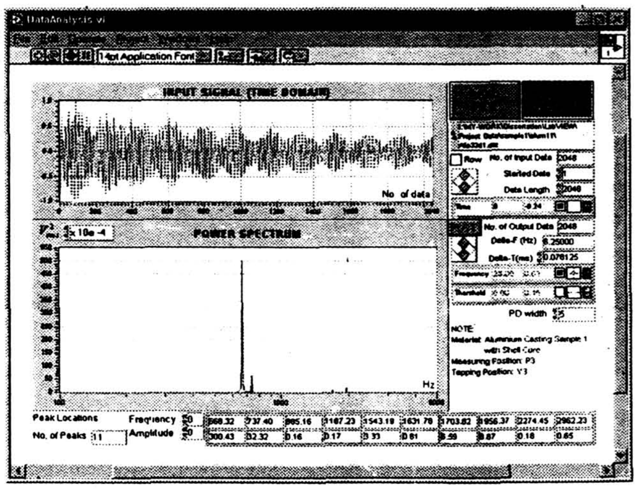


Fig. 5 The plot in time domain and frequency domain by using LabVIEW software

Normally, the motion of vibrating body can be converted into an electrical signal by a vibration transducer in time domain. The time domain signal is a plot of amplitude versus time. Fast Fourier Transform (FFT) is a mathematical operation that transform a signal from the time domain to the frequency domain. This study uses Auto Power Spectrum VI based on FFT in an analysis module of LabVIEW software. The plot of the result is in power spectrum versus frequency. Figure 5 shows the plot of time domain and frequency domain using LabVIEW software.

3. Experiment

Bump test is the method that used to determine the natural frequency of vibrating body as shown in Figure 6. Experimental rigs compose of an accelerometer, amplifier, spectrum analyzer and PC computer with LabVIEW software. In the experiment, the body is hung with one or more accelerometers attached. The body is then tapped with a small hammer and the results from the spectrum analyzer are collected with the help of LabVIEW software into a file for later analysis.

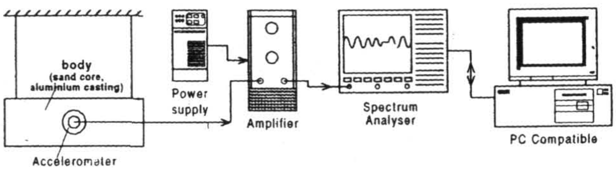


Fig. 6 Experimental rigs for measuring vibration

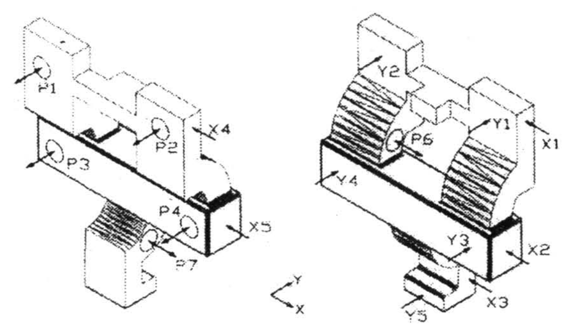


Fig. 7 The measuring and tapping position on shell core.

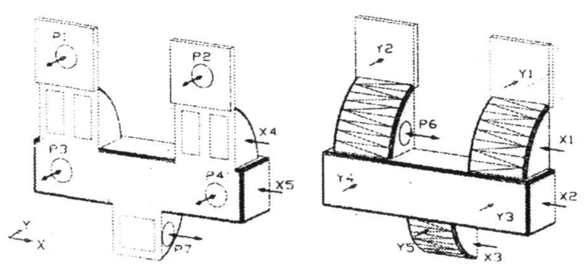
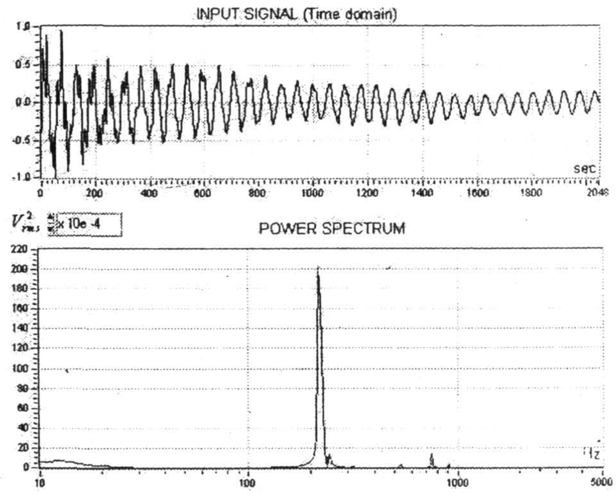
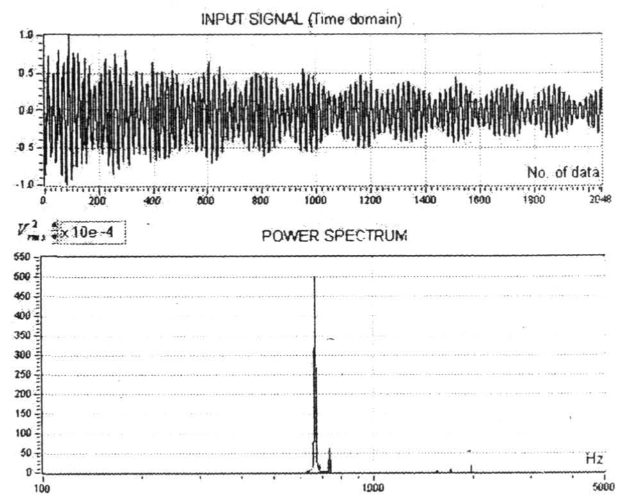


Fig. 8 The measuring and tapping position on aluminium casting.

Experiments are carried out an shell core and aluminium casting. The measuring and tapping position are shown in Fig. 7 and 8. P1-P4 represent measuring positions on Y-direction and P5-P6 in X-direction. X1-X5 and Y1-Y5 represent tapping position in each direction respectively. Exampie of experimental data are shown in table A1 and A2 of the Appendix. Figures 9 and 10 show the plot of experimental data in time and frequency domains. Data in time domain are read from the spectrum analyzer and collected with the help of LabVIEW software. In the time domain plot of Fig. 9, the time interval between sampling is 0.078125 ms. And the range of voltage represented by the amplitude in Y-axis is between –1 and 1. It is clear from Fig. 9 and 10 that the natural frequencies are at the peaks of the plots in the frequency domain.



(a) Shell core



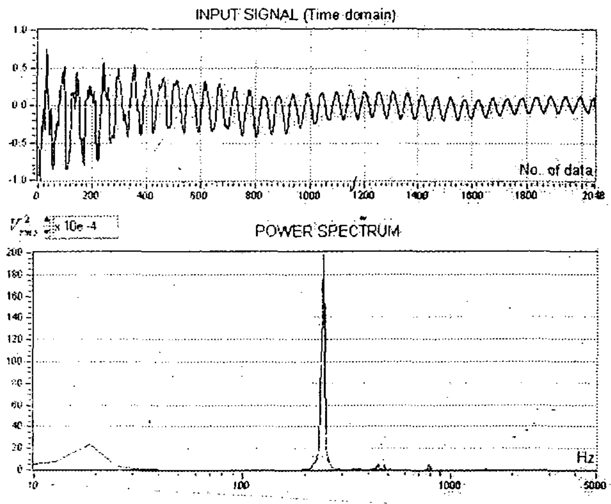
(b) Aluminium Casting

Fig. 9 The plot of experimental data and Power spectrum of each body in Y-direction.

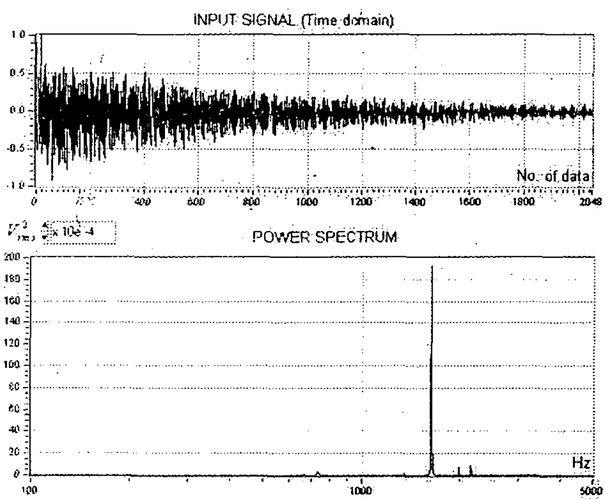
4. Results and Discussions

Consider first the result in the X-direction, the main natural frequency of the shell core (Fig. 9(a)) is about 200-220 Hz. For aluminium casting as shown in Fig. 9 (b), the main natural frequency is about 660-680 Hz. In Y-direction, the main natural frequency was about 240-250 Hz for shell core and 1620-1630 Hz for aluminium casting. The main natural frequency of aluminium casting is always higher than shell core. In addition, there are other frequencies with small amplitudes around 10-2000 Hz.

The main natural frequency of the vibrating bodies in Y-direction is more important than another direction. As shown in Fig. 3, body is clamped in Y-direction and pneumatics hammer also hit the body to loose up shell core in Y-direction. From the knock out process, shell core is removed from aluminium casting. Therefore, the main natural frequency of shell core should be the frequency range of knock out process that was about 200-220 Hz in Y-direction.



(a) Shell core



(b) Aluminium casting

Fig. 10 The plot of input signal and power spectrum of vibrating bodies in X-direction.

5. Conclusion

The experimental method can be used for determining the main natural frequency of a complex body when mathematical form cannot model the system. The experiment set up can collect, analyze and present the experimental data and result. From this study, the main natural frequency of shell core as shown in Figs. 9 and 10 is about 200-220 Hz. in Y-direction and 240-250 Hz. in X-direction. The frequency that should be used in the knock out process is therefore about 200-220 Hz. Additional experiment in knock out process using the main natural frequency of shell core should be carried out in the future to verify this study.

6. Acknowledgment

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Appendix

Table A1 Frequency spectrum of aluminium casting

No. of data = 2048 Sampling frequency = 12.8 kHz.

Delta-T = 0.078125 msec. Delta-F = 6.25 Hz.

Measuring Position		Tapping Position										*Result*	
		Y1		Y2		Y3		Y4		Y5			
P1	Frequency	681	1319	682	1319	681	738	681	1319	681	1319	*681*	*1319*
	Amplitude	63.6	780.5	26.3	351.4	431.8	17.6	346.3	25.9	37.1	520.3		
P2	Frequency	662	1319	662	1319	662	738	662	738	662	1319	*662*	*1319*
	Amplitude	100	374.9	26.8	425.4	73.4	42.7	489.1	32.2	87.1	217.2		
P3	Frequency	669	1956	669	1956	669	738	669	738	669		*669*	
	Amplitude	107.6	209.8	54.3	152.9	504.5	65.6	839.8	67	317.7			
P4	Frequency	662	1319	662	1319	662	738	662	738	662	1319	*662*	
	Amplitude	154.7	66.3	92.5	56.1	377.9	36.7	201.8	11.4	13.9	83.5		
		X1		X2		X3		X4		X5			
P6	Frequency	1306	1631	1306	1631	1306	1631	1306	1631	1306	1631	*1306*	*1631*
	Amplitude	30	25	10.3	39.4	43.2	29.1	44	21	12.8	36.1		
P7	Frequency	1625		1625		669	1625	1625	2162	1625		*1625*	
	Amplitude	193.6		254.5		11.2	89.5	67.2	46.8	249.2			

Note: Unit of Frequency = Hz , Amplitude = $V_{rms}^2 \times 10^{-4}$

Table A2 Frequency spectrum of shell core

No. of data = 1024 Sampling frequency = 12.8 kHz.

Delta-T = 0.078125 msec. Delta-F = 12.5 Hz.

Measuring Position		Tapping Position										*Result*	
		Y1		Y2		Y3		Y4		Y5			
P1	Frequency	250	406	250	406	181	562	188	250	400	562	*250*	
	Amplitude	45.2	32.2	130.1	35.4	137.7	55.5	34.1	137.3	62.5	34.6		
P2	Frequency	194	238	194	425	238	425	194	425	194	419	*194*	
	Amplitude	93	22.1	27.6	46	215.8	62.8	232.8	28.3	38.6	83.8		
P3	Frequency	219	531	225	238	219	244	219	238	219		*219*	
	Amplitude	82.6	19.8	41	133.6	202.4	14	229.2	119.7	685			
		X1		X2		X3		X4		X5			
P4	Frequency	244	444	219	244	219	244	219	725	219		*219*	
	Amplitude	118.9	57.2	351.7	14.9	621.9	117.3	362.8	27.5	1123			
P6	Frequency	250		250		250		250	462	250		*250*	
	Amplitude	87.4		370.5		221.9		89.5	24.2	109.3			
P7	Frequency	244	344	244	344	244		244	344	244		*244*	
	Amplitude	12.9	12.9	24.9	9.1	198		8.2	12.1	69.7			

Note: Unit of Frequency = Hz ;Amplitude = V^2 $\times 10^{-4}$