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ON SOME DYNAMIC ASPECTS OF RADIAL DRILLING MACHINE

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ABSTRACT
In the present work experiments have been done to study the effect of cutting parameters on dynamic characteristics of a radial drilling machine. The cutting parameters considered are spindle speed and feed. Several directions have been considered for measuring the vibrations with the sensor i.e. the accelerometer placed at a suitable position near the spindle of the radial drilling machine. A digital oscilloscope has been used in the experiments at FFT mode to plot the vibration signal (dB) on frequency domain. The data has also been obtained on time domain. The results obtained have been used to find the relationship between spindle speed and the level of vibration. The trend between feed and vibration signal has also been established. Further the frequencies corresponding to peak vibration amplitudes at varied conditions of feed and speed have been identified. In the next phase of the work finite element analysis of the radial drilling machine structure has been done by using ANSYS 5.4 software for the purpose of identifying the natural modes of vibration. The natural frequencies of the first few modes have been compared with the frequencies recorded through FFT analyzer during experimental study under varied conditions of drilling. This comparison shows that frequencies, obtained though finite element technique, are in no way matching or closer to the frequencies of vibration during actual machining (i.e. drilling) at different speeds and varied feeds. It is likely therefore, that the chances of severe vibration are remote. Mode shapes have also been presented.

Keywords: Vibration, Finite element, Feed, Spindle speed, Frequency.

1. INTRODUCTION

Even if chatter does not occur, machine tools do vibrate. Process parameters may influence the level of vibration in chatter free normal condition as well. It is desired that machine tools be dynamically strong under the influence of interaction between the structural dynamics and the dynamics of the cutting process at varied machining conditions. So like any other machine tools, it is important for radial drilling machine also that its dynamic performance is satisfactory. The influence of process variables of radial drilling machine is, therefore, of significance.

In so far as state of the art is concerned a large number of publications can be referred in the area of machine tool dynamics. Tobias [1] and Tlusty [2] made large number of studies to predict the limiting width of cut so that chatter might be avoided. Chatter vibration of long drills have been experimented and analyzed by Ema *et al*. [3] and they showed that the vibration was due to regenerative effect. Tarng and Li [4] developed simple methods to predict chatter limit in drilling process. Hemwani *et al*. [5] studied the effect of different cutting parameters on vibration of radial drilling machine. This particular aspect has not been investigated earlier to any fair extent. Chandrasekharan *et al*. [6] developed a model to predict the cutting force for drilling of metals and reinforced composite materials. It has been reported that although modeling machine tool dynamics was common for turning and milling, relatively few research works had been done for drilling [3].

In the analysis of machine tool vibration, application of finite element method may prove to be useful. The structure of radial drilling machine has, however, not yet been given adequate emphasis for consideration of vibration analysis through finite element technique.

Keeping the above points under consideration, in the present work some aspects of vibration have been studied for a radial drilling machine. The work includes experimental investigation and finite element analysis. In the experimental part the change in vibration level has been studied under varied levels of speed and feed. Finite element method has been employed for mode-frequency analysis of the drilling machine structure.

2. EXPERIMENTATION

Vibration has been sensed by an accelerometer placed near the spindle of the radial drilling machine (location P). Measurements of vibration signals have been made in three mutually perpendicular directions X, Y and Z. The direction Z is parallel to the spindle axis. The direction X is perpendicular to both the spindle axis and length of the arm The direction Y is perpendicular to the spindle axis

and parallel to the length of the arm. An FFT analyzer has been employed to record the vibration signal both on frequency and time domains. On frequency domain, the signals have been recorded and plotted in dB, while on time domain in mV. Drilling operation has been done on solid material with a twist drill of ½ inch (12.7mm) diameter. Different levels of spindle speed and feed have been used in the experiments. The results are discussed in section 4.
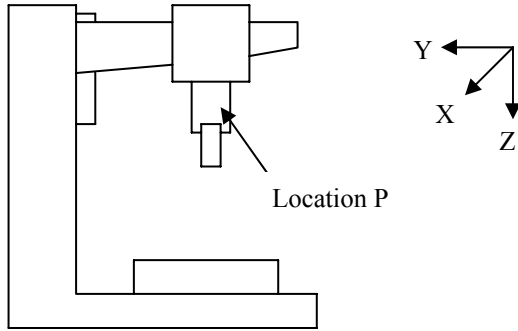

Fig 1. Experimental Set-up

3. FINITE ELEMENT ANALYSIS

The objective of finite element analysis has been to determine the natural frequencies of vibration of fist few modes and the corresponding mode shapes of the structure. For free un-damped vibration, the governing equation of motion of the discretized system is represented by:

$$[M]\left\{\ddot{X}\right\} + [K]\left\{X\right\} = 0 \tag{1}$$

where, [M], [K] are global mass and stiffness

matrices respectively; $\{X\}$, $\left\{\ddot{x}\right\}$ represent the

displacement and acceleration for all the elements of the structure as a whole. The element matrix is given below:

$$[m] = \int \rho [N]^T [N] dv \tag{2}$$

And the element stiffness matrix [k] is obtained through the following formulation:

$$[k] = \int_v [B]^T [D][B] dv \tag{3}$$

ρ is the density of the material, N is a suitable and valid shape function such that $\{u^*\}=[N]\{x\}$ where u* represents displacement field vector for an element while $\{x\}$ is the matrix of displacement vector, [D] is elasticity matrix & [B] is given by $\{\varepsilon\}=[B]\{x\}$ in which $\{\varepsilon\}$ is a matrix of element strain vector, v stands for volume. The structure of the radial drilling machine has been discreetised with ANSYS 5.4 software. Consistent mass matrix has been employed in 2-D finite element modeling of the structure of the radial drilling machine

for dynamic analysis. As per ANSYS 5.4 codes, the types of elements used are: plain 42 (four nodded) axi-symmetric (for column), 4 noded plain strain -plain 42 (for radial arm and bed), 2 nodded – beam 23 (for spindle). Analysis has been done based on the formulation discussed above, which finally takes the form of eigenvalue-eigenfunction problem given by

$$[K]\{X\} - \omega^2 [M]\{X\} = 0 \tag{4}$$

where ω^2 represent eigenvalue and $\{X\}$ is now the eigenvector. For non-trivial solution

$$[K] - \omega^2 [M] = 0 \tag{5}$$

For an n-th order determinant in the above equation one can obtain natural frequencies and then going back to Eq. 4, n natural mode shapes or eigenvectors are determined. Results are discussed in Sec.5.

4. DISCUSSION ON EXPERIMENTAL RESULTS

4.1 Effect of Spindle Speed

Figs. 2-3 illustrate how change in speed has effected variation in vibration signal. It is found from these figures that, except for drill rpm= 240, with increase in rotational speed, level of vibration increases. Vibrations are generally more in the direction Z. As the drill has penetrated into the work, the guidance afforded by the hole restricts vibration in the directions X and Y. Low level of vibration in the directions X and Y is desired because vibration in these directions will have direct influence on the accuracy and surface quality of machined hole. Increase in vibration level with increase in spindle speed can be explained by the fact that the effect of different types of error in the kinematic chain is more when drill rpm is higher. Some specific and major inaccuracies may be associated with the kinematics of the drilling machine in respect of the spindle speed = 240 rpm, at which the general trend is violated. Vibration signals in dB, recorded on frequency domain, for two different speeds are shown in Figs. 4-5. Frequency corresponding to maximum amplitude has been noted for each experimental observation. Typical values in one set of experiments (320 rpm, 0.007 inch/rev.) are: 5.40, 5.45 and 6.10 kHz in the directions X, Y and Z respectively. Vibration signal has been recorded on time domain as well (Fig.6).
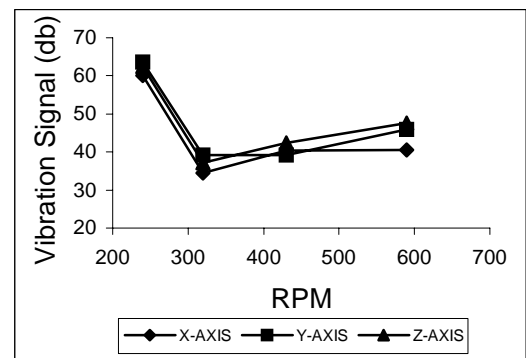

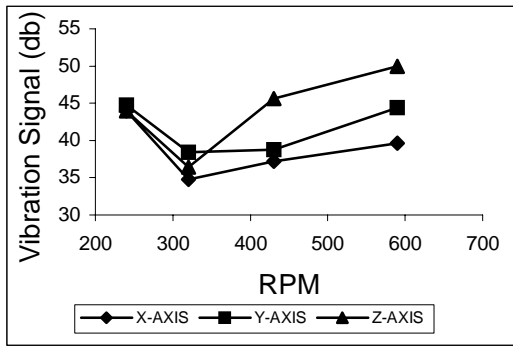Fig 2. Effect of Spindle Speed on Vibration at Feed 0.004 inch/rev.

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Fig 3. Effect of Spindle Speed on Vibration at Feed 0.011 inch/rev.
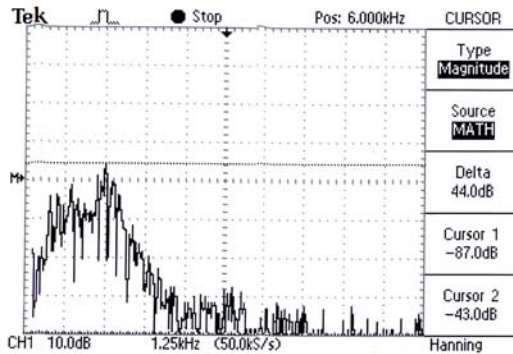

Fig 4. Vibration on Freq. Domain at 240 rpm, feed=0.004"/rev, drill dia.=0.5", dir. Z
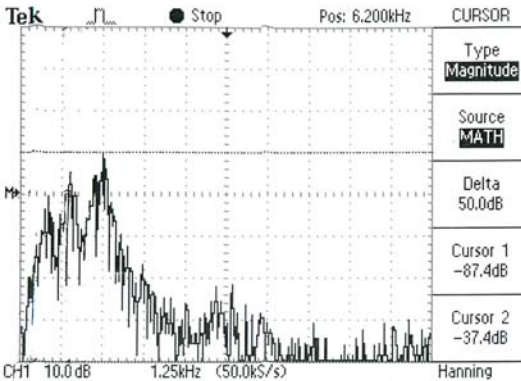

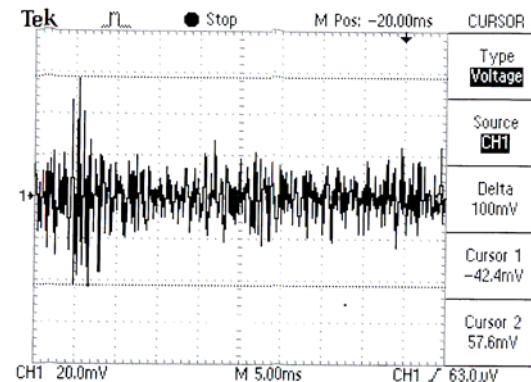Fig 5. Vibration on Freq. Domain at 590 rpm, feed=0.004"/rev, drill dia.=0.5", dir. Z

Fig 6. Vibration on Time Domain at 320 rpm, feed=0.004"/rev, drill dia.=0.5", dir. Z

4.2. Effect of Feed

The Figs. 7-8 indicate the relationship between feed and vibration signal, as revealed from experimental data. Though the trends shown in these figures are not entirely conclusive, vibration is more if feed is large. Further it appears that, generally, in the direction X, the vibration level is smaller. In the dynamic model developed by Yang et al. [7], differential equations in X and Y directions were considered (letting off Z direction). This gives an idea that vibration in X (& Y) directions is (are) important and required to be small. The authors also
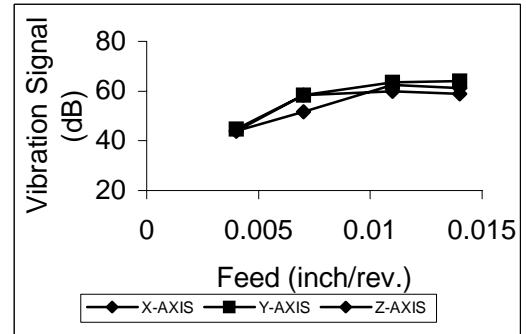

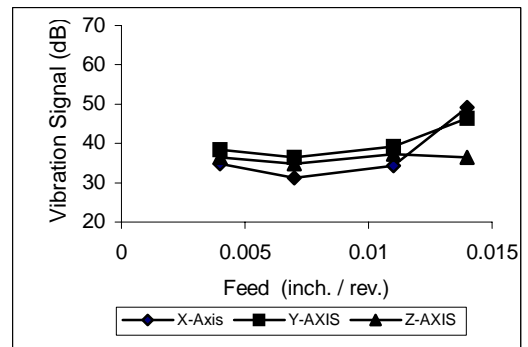Fig 7. Effect of Feed on Vibration at Spindle Speed 240 rpm

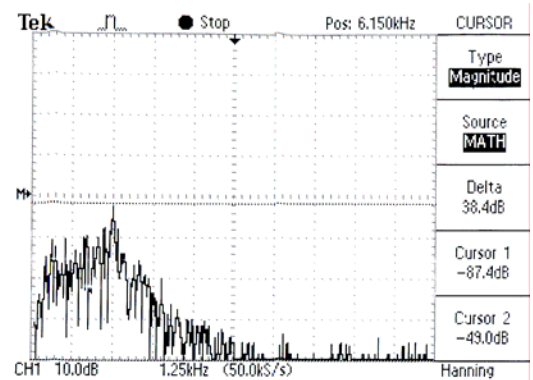Fig 8. Effect of Feed on Vibration at Spindle Speed 430 rpm

Fig 9. Vibration on Freq. Domain at feed=0.007"/rev, 430 rpm, drill dia.=0.5", dir. X
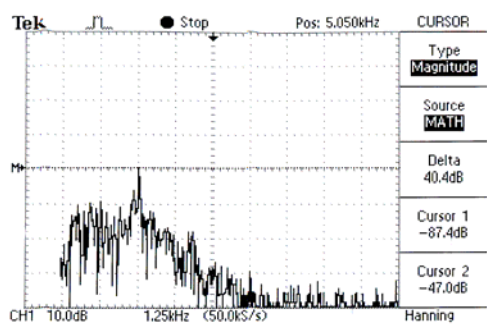
Fig 10. Vibration on Freq. Domain at feed=0.011"/rev, 430 rpm, drill dia.=0.5", dir. X

mentioned that larger the feed the larger would be vibration and hence ultimate possibility to have chatter. They expressed that element chip load is influenced by feed (and other factors) which greatly influence the vibration behavior in the drilling process. The results in the present study seem to be in conformity with the same. Further, feed may influence the value of coupling coefficient between the dynamic force and chip thickness variation, thereby affecting the vibration during machining. Computer printouts of the outputs of the FFT analyzer have been obtained at various feed-speed combinations, from which frequencies corresponding to peak amplitudes have been noted. Only two typical printouts are shown in Figs. 9-10. (All the experimental frequency values are not presented here separately).

5. DISCUSSION ON THE RESULTS OF FINITE ELEMENT ANALYSIS

Natural frequencies of the first six modes of the radial drilling machine structure have been found to be 0.277E-03Hz, 149.135Hz, 333.047Hz, 927.847Hz, 994.395Hz and 1603 Hz respectively by FEA. None of the above frequencies & the frequencies of the still higher modes (not mentioned here) are matching with or becoming closer to any of the frequencies observed during experiments carried out under varied conditions of speed & feed. The experimental frequencies varied in the range around 4 to 6 kHz, in rare cases: 2.85-3.8 kHz). So possibility of severe vibration /chatter is remote. Figs. 11-12, Show 1st and 2nd modes of vibration of the radial drilling machine. In the first mode there is almost no deflection of any part/portion of the drilling machine structure, exception being spindle. Spindle deflection is noticeable. In the second mode, deflection of the spindle in the direction along the arm length is restricted;
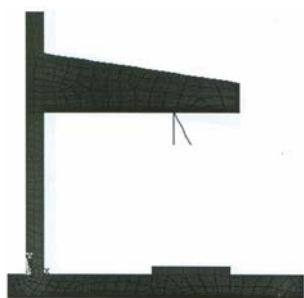

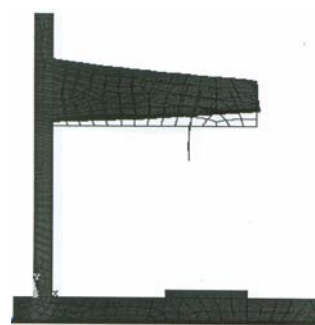Fig 11. 1st Mode Shape (Frequency=0.277E-03 Hz)

Fig 12. 2nd Mode Shape (Frequency=149.135 Hz)

but the arm itself vibrates in a manner as if it moves up and down about the column. In the higher modes (up to 12th), not shown here, deflection of the bed, column and radial arm has been noticed. These mode shapes, however, have not been included here.

6. CONCLUSIONS

The trends in vibration signal with changes in speed and feed have been established. In general vibration signal is less in X and Y directions in comparison to Z direction. Vibration signals have been analyzed on frequency domain at different cutting conditions. Modes of free un-damped vibration of the drilling machine structure have been determined by FEA. Frequencies of the first and several consecutive higher modes, as determined by FEA, in no way do match or come close to those observed in the experiments. Possibility of severe vibration in machine tool structure in the set of conditions used in the experiment is remote.

7. REFERENCES

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