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## Machine Foundations in Power Plant and Other Industries- Case Studies

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# Machine Foundations in Power Plant and Other Industries - Case Studies

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**SYNOPSIS** Studies on dynamic behaviour of turbo-generator foundations of various ratings have been carried out. Salient response parameters have been identified. Field vibration measurements taken on a 200 MW T.G. foundation have been reported. Measurements taken under intermittent coast-up and constant speed conditions have been analysed using FFT analyser and the frequency response thus obtained has been presented and discussed. From the signature analysis, high vibration peaks associated with the soil vibration modes have been observed. Analytical study carried out for 200 MW TG foundation also indicated the significance of soil structure interaction effect on the dynamic response. Based on the results of the analytical and experimental studies, recommendations have been made to include the soil structure interaction effect for dynamic response calculations.

## INTRODUCTION

Machines are a vital part of the total industrial set up. In power plants and industries, the malfunctioning of these machine may result in total loss of power or production. In many cases where the foundations of these equipment have been found to be the cause of such malfunctions, it takes a long way to provide the remedial measures. Various aspects such as vibration of individual elements of the foundation, coupling effects between these elements, effects of various types of mounting of machines on the foundation etc., are at present not considered in the design. However, field vibration measurements provide an insight into the same and may provide certain checks and guidelines to be implemented at the design stage so as to ensure the smooth running of the machines.

Identical machines having identical foundations have been observed behaving differently under different soil conditions. Soil structure interaction study thus becomes important for the proper design of the foundation. This is more so for the frame foundation where this effect is generally ignored at the design stage for computation of dynamic response.

With the aid of fast computers and advanced analytical techniques, it has become possible to model and analyse foundations in more detail for computing both dynamic and static response. The effect of soil can also be incorporated using appropriate soil models. However the use of these advanced analysis procedures has been found to be limited to research works only whereas conventional simplified approaches still find appropriate position in the design organisations. This clearly indicates the lack of efforts in translating research findings into simplified design

procedures which is a must as this only would ensure the application of research in practice. However the real application will still remain incomplete unless the findings from field observations are also incorporated into design procedures. With the advancement and sophistication in the vibration measuring instruments it has become possible to more precisely measure the dynamic response of the machines and their foundations. Signature analysis of field vibration records provides identification of the cause and source of faults responsible for malfunctioning of the machines. It may be worthwhile to mention that excessive vibration caused due to the faults in the machine could however be rectified whereas those due to the foundations are difficult, if not impossible, to be rectified. Hence, it is necessary to incorporate into design those effects of the foundation as identified by field vibration tests.

## DYNAMIC RESPONSE

Studies have been carried out on turbo-generator foundations of various ratings to study their dynamic response. Vibration measurements on the machine and the foundation have been taken on instrument tape recorder with the help of vibration pick-ups. The signatures thus obtained have been analysed for the frequency response using Fast Fourier Transform (FFT) Analyser. In some cases direct amplitudes have been recorded for spot evaluation of the response. Analytical studies have been carried out on 120 MW and 200 MW TG foundations both including and excluding soil structure interaction. Vibration measurements on two identical foundations constructed side by side have been taken and the variation in their response, as observed, has been discussed. In order to

study the influence of soil on the dynamic response, vibration measurements on two identical foundations having identical machines but different soil conditions have been taken and the comparative effects of soil on the dynamic response have been discussed. To study the vibration transfer mechanism from the machine to the foundation, vibration measurements have been taken on the bearing pedestals along their heights and simultaneously measurements have also been taken on the foundation in the close vicinity of the bearing pedestal. To identify the frequency response of various elements of the machine and the foundation, vibration measurements have been taken at frequent intervals of the speed of the machine. To study the effect of load (output) of the machine, vibration measurements have been taken on no load, part load conditions and the results thus obtained have been discussed.

## RESULTS AND DISCUSSION

Vibration measurements on a 200 MW TG foundation have been taken. Fig. 1 shows the location of the vibration pick-ups on the top deck of the foundation. Uniaxial and triaxial vibration pick-ups as well as seismic pick-ups have been used for vibration measurements. A four channel instrument tape recorder has been used to record the signals. Signals have been recorded both in transverse and vertical directions. Vibration signals from the tape recorder are analysed for frequency response with the help of FFT analyser. Frequency response of the foundation at constant speeds as well as under coast-up conditions have been shown through Fig. 2 to Fig. 11.

Figs. 2 and 3 show the horizontal and vertical responses for coast-up condition in the speed range of 30-500 rpm. Figs. 4 and 5 show the horizontal and vertical responses for a constant speed of 500 rpm. Figs. 6 and 7 show the horizontal and vertical responses for coast-up condition in the speed range of 500-1200 rpm. Figs. 8 and 9 show the horizontal and vertical responses for a constant speed of 1200 rpm. Figs. 10 and 11 show the horizontal and vertical responses for a constant speed of 3000 rpm.

Figures 2 to 11 show the variation of acceleration with the frequency. The displacement amplitude at any frequency level can be obtained by dividing the acceleration amplitudes by square of the frequency (rad/sec). The acceleration recording is preferred as it will show a large acceleration peak at the higher frequencies even if the displacement is relatively very low. However large acceleration peaks at high frequencies do not significantly add to overall amplitude levels.

In these records vibration peaks have been observed at frequencies less than and higher than running speed of the machine. This indicates that excitations also take place at speeds lower/higher than the operating speeds. Hence excitations at low frequencies may cause resonance with the corresponding soil-struct-

tural frequencies giving rise to larger amplitudes.

The peaks observed at 4.5 Hz, 6.25 Hz and 7 Hz in figures 2,3,4,5,10 & 11 indicate the presence of some member frequencies in this range. Normally the frequencies corresponding to soil deformation modes are found to be in this range. From this, one can derive that soil-structure interaction can give rise to peaks at low frequencies which predominantly add to the overall response of the foundation.

The peaks in the range of 14 Hz, 21 Hz are indicative of the presence of some structural sub-element frequencies which are normally not computed in design, as the present design practices do not call for the same. Hence, in addition to the main structure members considered in design for dynamic response, it may also be required to compute the frequencies of structural sub-elements and obtain the response for transient resonance conditions.

The peaks at higher frequencies indicate the presence of higher member frequencies which may correspond to structural frequencies in higher modes of vibration. Since, higher frequency peaks do not significantly add to the overall response of the foundation, these can be disregarded from the point of view of foundation design. However, these peaks have their role to play in relation to the health of the machine.

Direct amplitude (displacement) measurements have been taken during coast-up from 1000 to 3000 rpm. Machine was then made to run at constant speed of 3000 rpm. Load was increased first to 10 MW and after some time to 70 MW. Amplitude of vibrations were recorded at both these load conditions. Amplitudes thus recorded have been shown in Figs. 12 and 13. It is seen from these figures that peaks have been observed at the critical speeds of the rotors. Also it is seen that amplitudes do show an increasing trend with the increase in loads, however the increase in amplitude is relatively small. Measurements taken on another machine (results not reported here) do not show any increase in amplitudes with the variation in load. Hence the observation that the amplitudes increase with the load cannot be generalised.

Fig. 14 shows the vibration measurements taken along the length of the top deck for two identical foundations located on different soils i.e. hard rock and alluvial soil. The measurements have been taken between bearing No.3 and bearing No. 5. It is seen from this figure that vibrations are high for hard rock conditions. This, thus, indicates that even in the case of hard rock, soil-structure interaction cannot be ignored. Hence, in hard rock conditions, designing the foundation with the fixed base assumption may lead to erroneous results.

Vibration measurements taken along the height of the column for two identical foundations in the same soil conditions have been shown in Fig. 15. It is seen that the amplitude levels

in one case are 2 to 5 times that of the other. Since it was difficult to draw a definite conclusion from these observations, vibration measurements were taken at the bearings, the analysis of which indicated that the cause of such a high vibration was the machine and not the foundation. The vibrations recorded at the bearing level are shown in Fig. 16.

Analytical studies carried out on TG foundations of 110 MW, 120 MW have shown the influence of soil structure interaction on the frequency response of the foundations. The structural frequencies tend to increase when soil effect is considered. Fig. 17 shows the increase in the structural frequencies for a typical foundation analysed as 2-D structure. Similar trend has been observed even in 3-D analysis. It is noteworthy to mention that soil-structure interaction indicates higher values of moments and shear forces over those when soil effect is ignored even in the static analysis.

#### CONCLUSIONS

From the observations made based on the analytical and experimental study reported herein, the following general conclusions are drawn:

Excitations not only occur at the running speed of machine but also occur at its sub and super harmonics.

Transient responses of the structural members including sub-elements must be considered in design.

It is not only desirable but necessary to include soil effects while designing the machine foundations both for dynamic and static response.

#### RECOMMENDATIONS

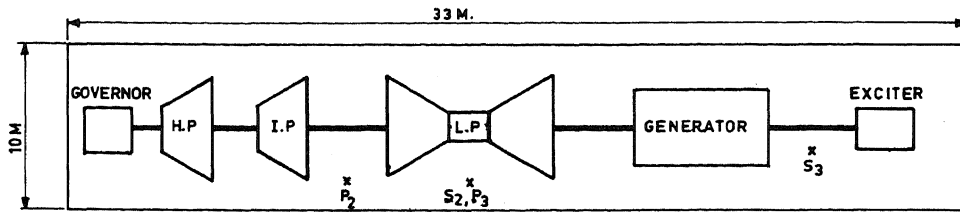
It is strongly recommended to form national bodies for carrying out field measurements on existing machine foundations. The data thus gathered should be exchanged freely with other national bodies. The large database thus formed shall help in better understanding of the behaviour of the machine foundations and may bring out new/additional factors required to be considered at the design stage.

#### ACKNOWLEDGEMENT

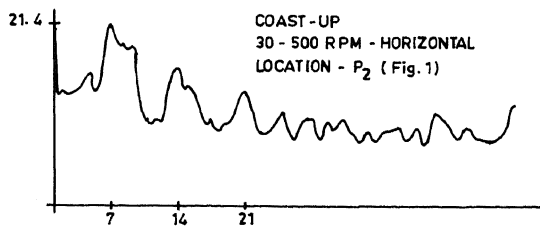
The author is thankful to Dr. A. Gopalakrishnan for his permission to publish the paper and for his constant encouragement to carry out the study. The author is also thankful to Mr. Anil Kumar Singh for conducting the field study. Thanks are also due to Mr. S. Satheesh for excellent drafting and Mr. P. Janardhana Rao for careful typing.

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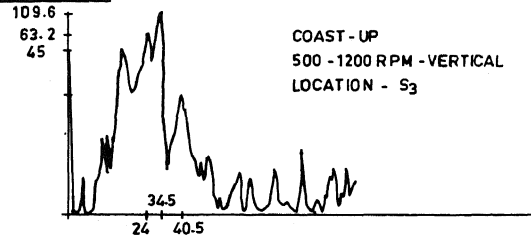
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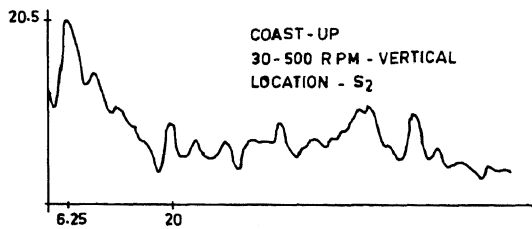
**Fig.1 LOCATION OF PICK - UPS**



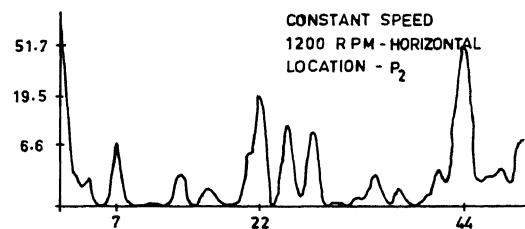
**Fig. 2**



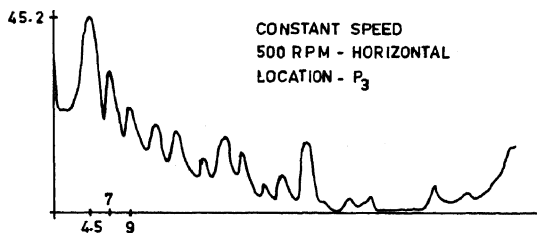
**Fig. 7**



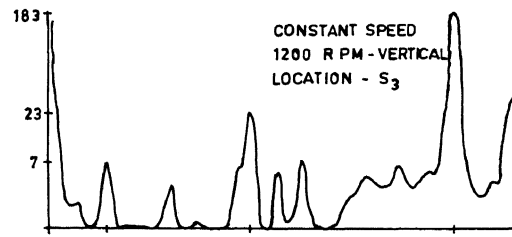
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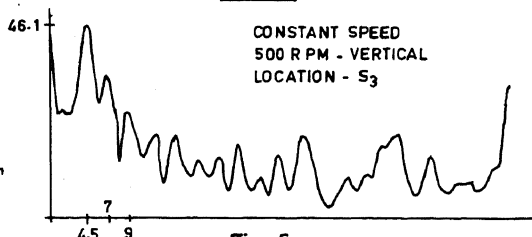
**Fig. 8**



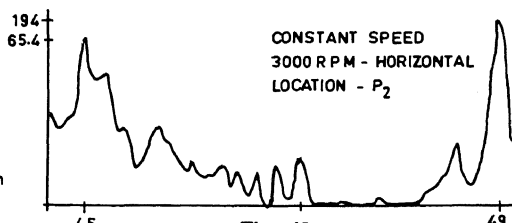
**Fig. 4**



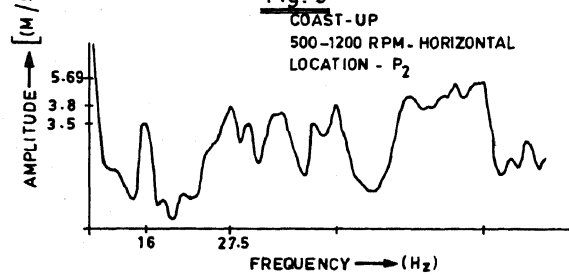
**Fig. 9**



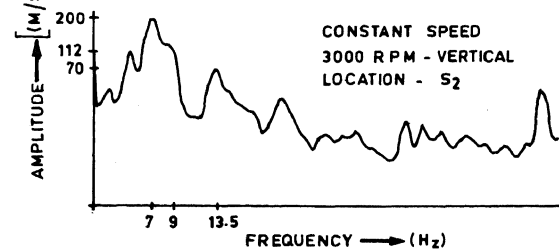
**Fig. 5**



**Fig. 10**

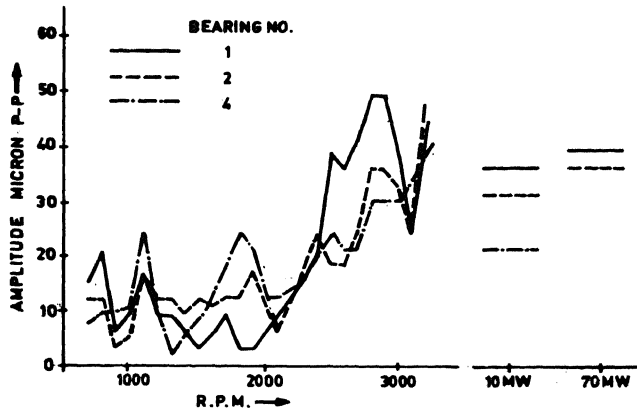


**Fig. 6**

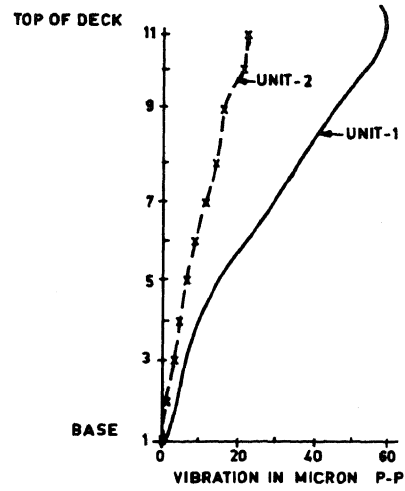


**Fig. 11**

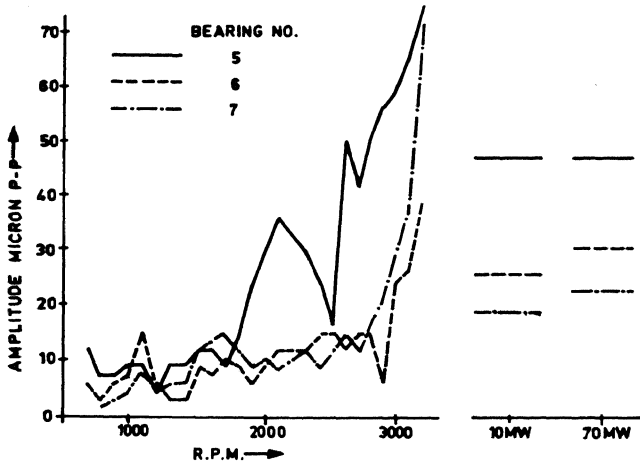
**FREQUENCY RESPONSE**



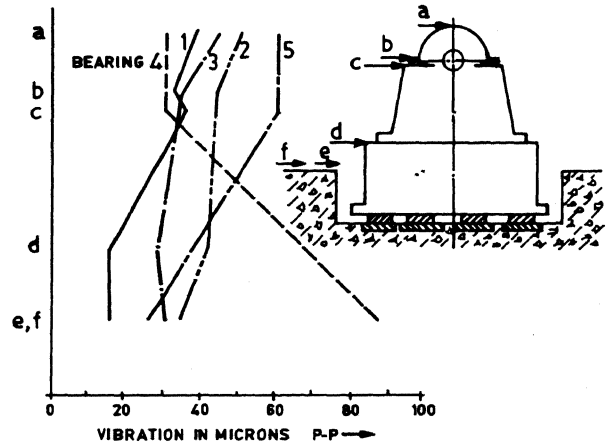
**Fig. 12 SPEED Vs. AMPLITUDES**



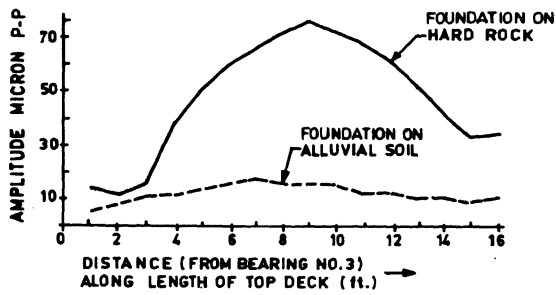
**Fig. 15 IDENTICAL FOUNDATION ON THE SAME SOIL**



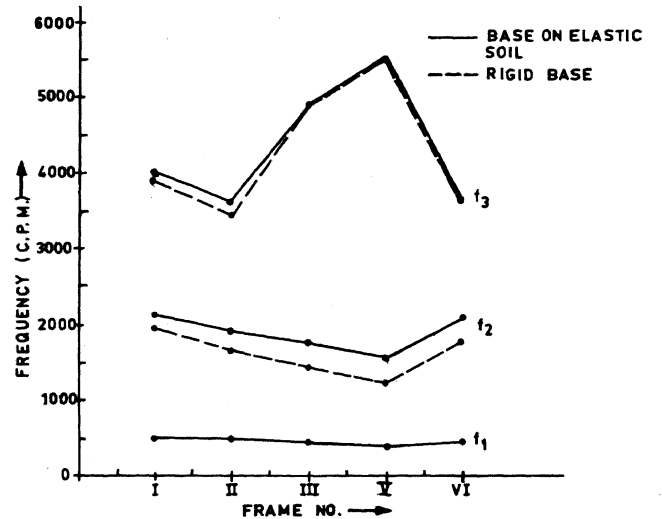
**Fig. 13 SPEED Vs. AMPLITUDES**



**Fig. 16 VIBRATIONS ON BEARING PEDESTAL**



**Fig. 14 IDENTICAL FOUNDATION ON DIFFERENT SOIL**



**Fig. 17 EFFECT OF SOIL ON NATURAL FREQUENCY OF FRAMES**