Analysis and Solution of Abnormal Vibration Problem of Exciter

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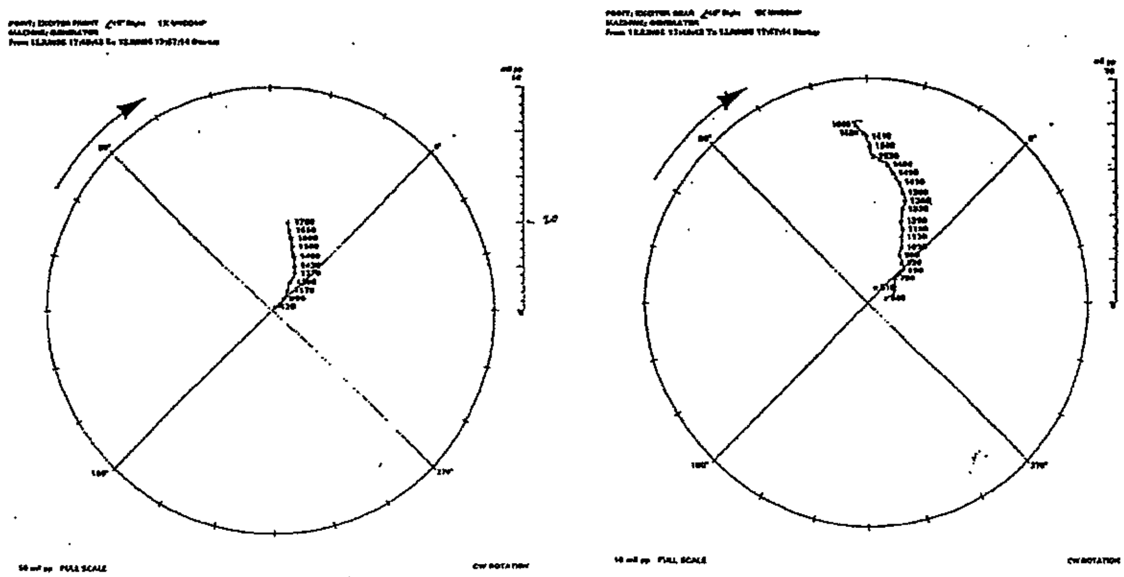
Abstract: This paper concerns the experimental and theoretical investigation of abnormal vibration on 1300 MW unit's exciter, which had been balanced in the BOS (Balance and Over Speed Facility) and had to be balanced in the field during the first run with exciter. Theoretical analysis of exciter shows that the exciter in field (on three bearings) had different vibrational characteristic comparing with that of BOS (on two bearings). This has changed the unbalance condition of exciter which had been well balanced in BOS. The recommended methods for making a good balance of the exciter both in field and in BOS are presented.

INTRODUCTION

During June of 1995, the 1300 MW unit 1 was in an outage in which the High Pressure, generator and exciter rotor were replaced; the Generator and exciter rotor were balanced (table I) in BOS[1]. On June 12th, unit 1 started its run up to rated speed--1800 RPM. The high vibration amplitudes on the exciter were in excess of 20 mils pk-pk filtered. The high pressure rotor shaft vibration amplitudes for the vertical and horizontal were both below 2.0 mils pk-pk filtered, the generator shaft reading slightly elevated. The excessive vibration was concluded to be from the exciter. The exciter was balanced in field by placing 1350 grams at 315 degree and removing 400 grams from 135 degree in the exciter main body, the shaft vibration of exciter was reduced to 2-3 mils (Fig.1, 2).

Table I Balancing result of 1300 MW unit's exciter in BOS

Speed	Coupling End Vertical		Coupling End Horizontal		Outboard End Vertical		Outboard End Horizontal	
	Amplitude	Phase	Amplitude	Phase	Amplitude	Phase	Amplitude	Phase
RPM	(mils)	(degree)	(mils)	(degree)	(mils)	(degree)	(mils)	(degree)
400	0.1	146	0.1	25	0.5	1	0.6	259
600	0.1	351	0.8	170	0.8	2	0.9	336
800	0.8	155	0.8	233	0.4	136	0.3	75
1000	0.5	144	0.8	242	0.2	186	0.6	158
1200	0.6	140	1.0	253	0.4	243	0.9	182
1400	0.7	136	1.2	264	0.6	260	1.2	196
1600	0.9	126	1.6	270	0.8	258	1.4	208
1800	1.3	138	2.0	288	0.9	259	1.5	206



Note: Reversed Rotation (Probe Reversed)

Fig. 1 Vibration polar plots of the exciter during starting up

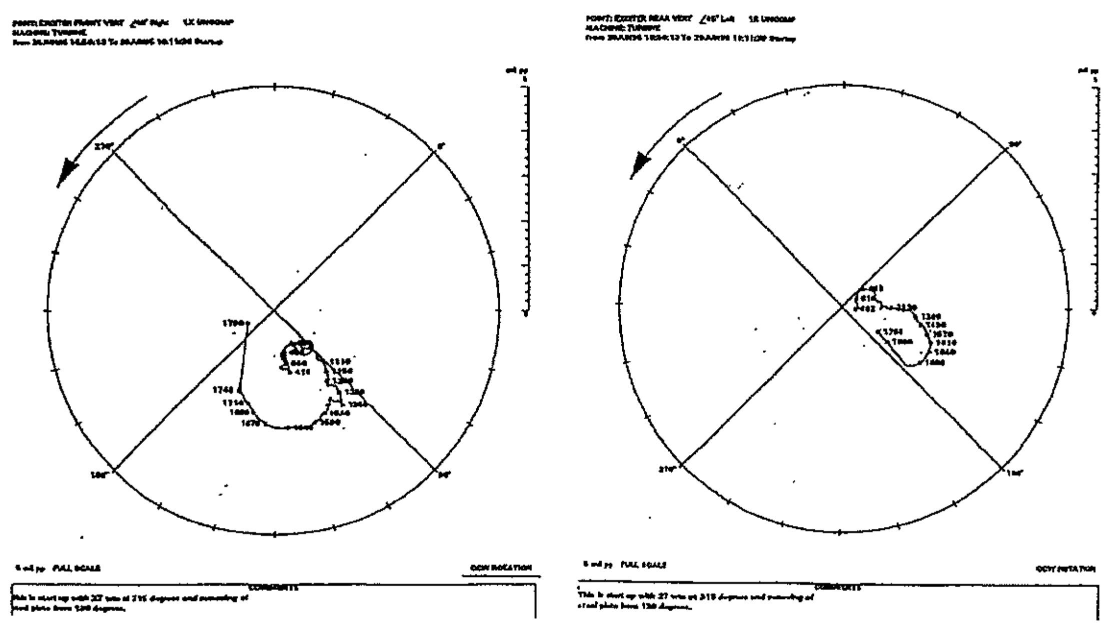


Fig. 2 Polar plots of the exciter's vibration during start up after being field balanced

In order to determine the reasons for abnormal phenomenon, the FEM (Finite Element Method) dynamical models of the exciter in BOS condition and in field condition were built, the calculation focused on two points: comparing dynamic properties of exciter supporting on three bearings with supporting on two bearings, and how to get a good balance of exciter both in BOS and in field.

THEORETICAL EQUATIONS

As illustrated in Fig. 3, the stationary coordinate system, XYZ is fixed in space, while the rotating coordinate

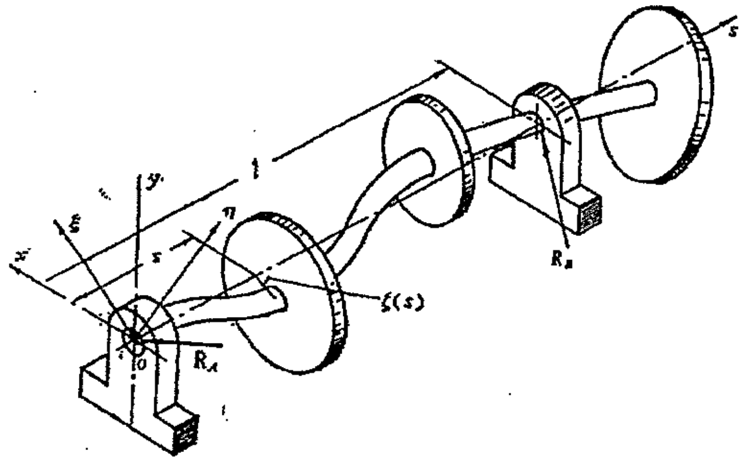


Fig. 3 Theoretical scheme of rotor

rotating coordinate system, oξηs, is fixed to the bearing centerline and rotates with rotor. The rotor deflection is of the form[2][3]

$$\zeta(s) = \xi(s) + i\eta(s) \tag{1}$$

Using the property of orthogonality of the modal characteristic functions, the unbalance distribution u(s) of rotor can be expressed as an infinite series of modal characteristic functions $\varphi_j(s)$ by

$$u(s) = \sum_{j=1}^{\infty} C_j m(s) \varphi_j(s) \tag{2}$$

the total rotor response (deflection $\zeta(s)$) for any particular speed is generally written as a sum of the individual modal response, as

$$\zeta(s) = \sum_{j=1}^{\infty} \frac{\Omega^2}{\omega_j^2 - \Omega^2} C_j \varphi_j(s) \tag{3}$$

where

$$C_j = \frac{1}{N_j} \int_0^l u(s) \varphi_j(s) ds \qquad \int_0^l m(s) \varphi_j(s) \varphi_k(s) ds = \begin{cases} 0 & (j \neq k) \\ N_j & (j = k) \end{cases}$$

$C_j = c_j e^{i\alpha_j}$ --- jth modal component in eccentricity distribution of rotor

c_j --- module of C_j

α_j --- phase angle of C_j

N_j --- jth modal mass

m(s) --- mass of unit length of rotor

Ω --- rotational frequency of rotor

ω_j --- undamped jth natural frequency of rotor

$\varphi_j(s)$ --- jth modal characteristic function

$\varphi_k(s)$ --- kth modal characteristic function

$\zeta(s)$ --- complex value representing rotor deflection (response or vibration) in rotating coordinate system

l --- rotor length

s --- distance from origin along the rotor axis

In equation (3), when rotational speed of the rotor equal to the critical speed for the jth mode, $\Omega^2/(\omega_j^2-\Omega^2)$ will reach a maximum, then jth modal response will dominate the rotor response of that speed, and the other modal responses will be neglected in general, so $\Omega^2/(\omega_j^2-\Omega^2)$ is an important factor of the rotor response. In order to balance the rotor, k correction masses $P_k=p_k e^{i\beta_k} (k=1,2,\cdots,k)$ are placed on the rotor, its location along the rotor is $s=s_k$, so the balanced rotor response is expressed as

$$\zeta(s)=\sum_{j=1}^{\infty}\left(\frac{\Omega^2}{\omega_j^2-\Omega^2}\right)\left[C_j+\frac{1}{N_j}\sum_{k=1}^{k}P_k\varphi_j(s_k)\right]\varphi_j(s) \tag{4}$$

Equation (4) shows that if rotational speed, critical speeds, and the modal shapes of rotor don't change, the balanced rotor response (vibration) will not be changed.

MODEL AND DYNAMIC ANALYSIS OF EXCITER ROTOR

The exciter rotor was simplified to lump mass and beam-type model using Finite Element program. Two generated finite element models were used for analysis of critical speeds and mode shapes for the exciter rotor(Fig. 3, 4), one is for BOS with two supporting bearings; the other is for Field with three supporting bearings.

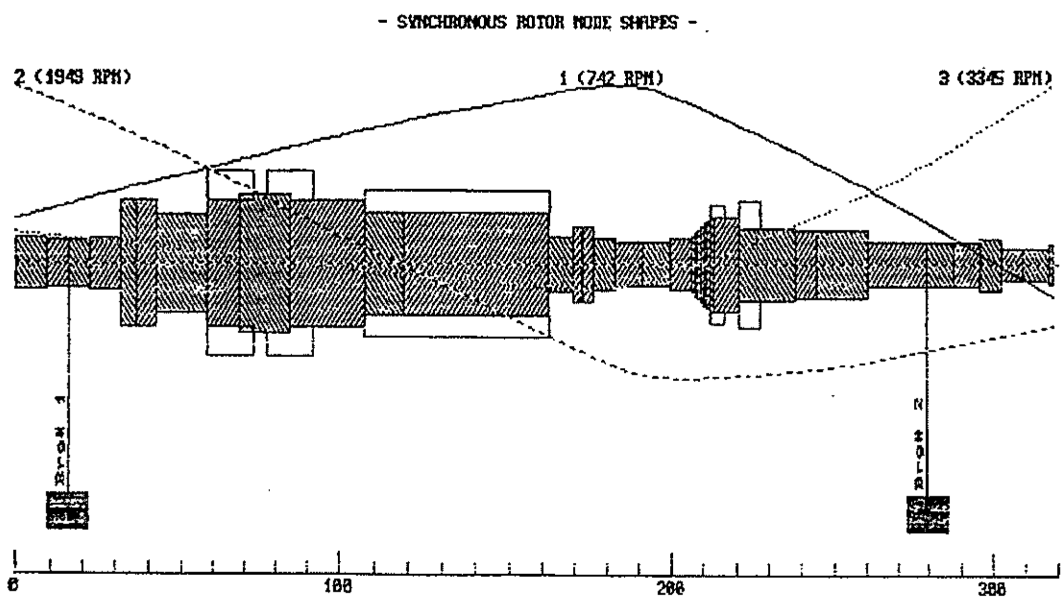


Fig. 4 Critical speeds and mode shapes of exciter in BOS

Table II Critical speed of the exciter

Critical speeds	First	Second	Third
BOS (on two bearings)	742 RPM	1949 RPM	3345 RPM
Field (on three bearings	1625 RPM	3201 RPM	4453 RPM

Comparing the dynamic characteristic of exciter in field with that of exciter in BOS, they had similar modal shapes, but the distribution of critical speeds of exciter were changed. In BOS at 1800 RPM, the rotational speed was near the second critical speed, so the exciter response was mainly controlled by the second modal response based on equation (4), the vibrational phases of two bearing of exciter at 1800 RPM are approaching opposite direction (see Table I), however in field at 1800 RPM, the rotational speed was near the first critical speed, the exciter response was chiefly controlled by the first modal response, the vibrational phases of two bearings(front and rear) are approaching same direction. The critical speed(RPM) location is heavily dependent on the stiffness of the bearings, support and its modal mass.

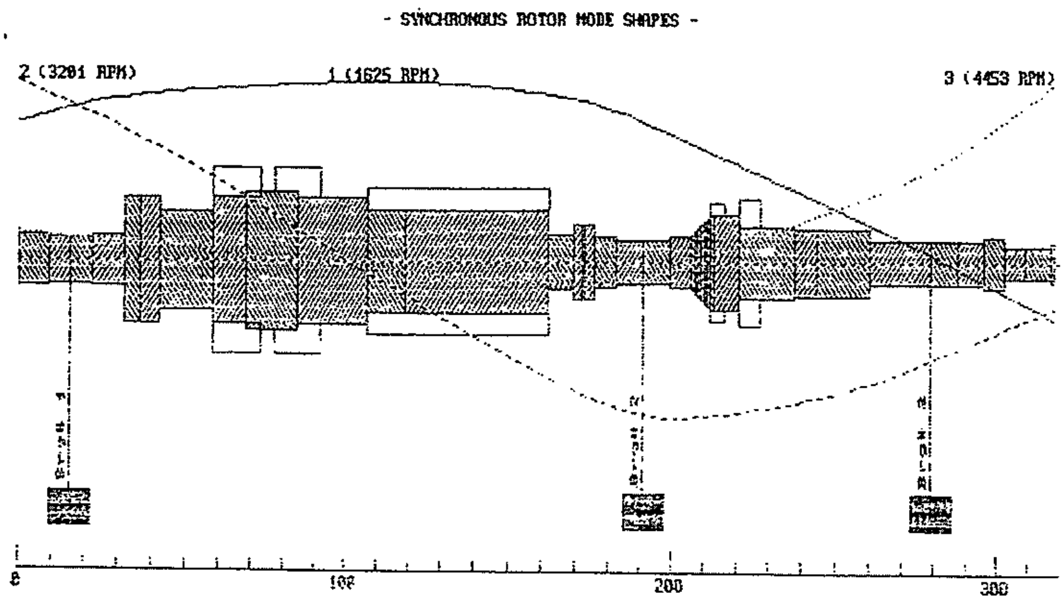


Fig. 5 Critical speeds and mode shapes of exciter in field

BALANCING METHODS OF EXCITER IN BOS

This type of exciter rotors operate in three bearings, sharing the third bearing with generator. When preparing to balance the rotor in the BOS, it was found that it is impractical to balance the exciter on three bearings due to practical limitation of installing a third bearing pedestal in the bunker. The calculations show that the balancing in front bearings (couple end and middle bearing) is not possible because of the excessive overhang of the outboard rotor end. By further calculation it was found that rotor can be balanced in two outboard bearings with stub shaft and that balancing in three bearings in the BOS is not necessary. Table III contains listing of the critical speeds for different bearings configuration and stiffness. It is interesting to note that the first critical speed in the field and second critical speed in BOS are at fairly close speed (see Fig. 4 and Fig. 5). Based on the experimental and theoretical investigation, several approaches to balancing were presented depending on the practicality in application.

Case 1, Only balancing the first critical speed of exciter in BOS, when stiffness of two supporting bearings were about 1.0E6 lb/in.

Case 2, 3 Balance the exciter in Low Speed Balancing Facility, because the operational speed (1800 RPM) is just over the first critical speed a little bit in field, the exciter can be regarded as semi-rigid rotor, two rigid mode of exciter should be balanced in Low Speed Balancing Facility.

Case 4 Balancing the first critical speed and operational speed (1800 RPM) of exciter in BOS, when stiffness of two supporting bearings are more than 2.8E6 lb/in.)

Case 5 Balancing the first critical speed and operational speed (1800 RPM) of exciter in BOS, the exciter in BOS has same vibrational character as that of in field.

Table III Balancing methods in BOS

case	Scheme of rotor	Stiffness (lb/in)	Support weight(lb)	Critical first	speed (RPM) second	Balance method
1		1.0E6	0	742	1949	only balance the first critical speed
2		5.6E4	4400	248 (rigid body mode)	415 (rigid body mode)	balance the two rigid body mode in low speed balance facility
3		2.24E4	2200	167 (rigid body mode)	293 (rigid body mode)	balance the two rigid body mode in low speed balance facility
4		2.8E6	0	854	2976	balance the first critical and 1800 RPM speed
5		2.1E6	0	1625	3201	balance the first critical and 1800 RPM speed

The above table shows that it is very crucial to observe the proximity of second critical speed to operating speed when rotor is balanced on two bearings in BOS. If stiffening of the supports is not fully functional, and 2nd critical mode is dominant at operating speed, no balancing should be done at operating speed in BOS.
After considering all variation, it was elected that the best viable option is case 1 for balancing in BOS and case 5 for balancing in the field. The whole solution given here stands on knowing the support stiffness and the accurate distribution of the critical speeds, specially the proximity of the second critical speed to the operating speed i.e. 1800 RPM.

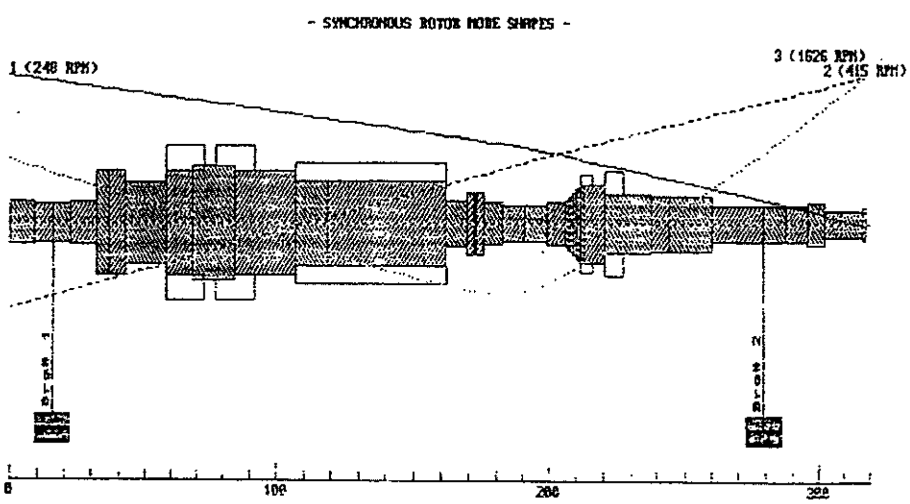


Fig. 6 Critical speeds and modal shapes of exciter (case 2)

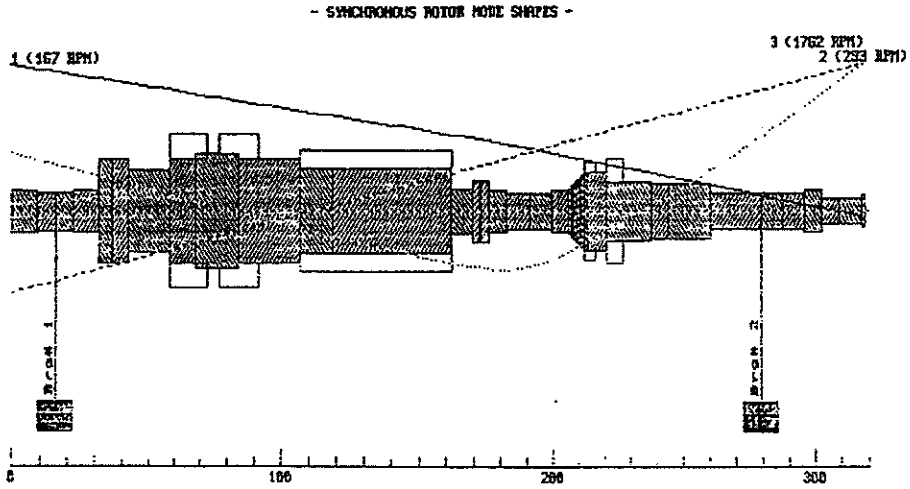


Fig. 7 Critical speeds and modal shapes of exciter (case 3)

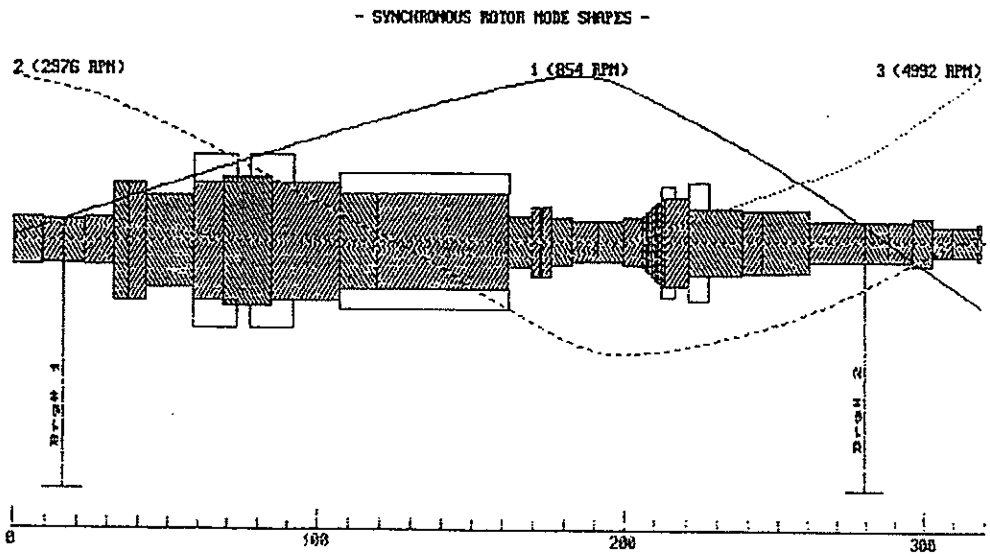


Fig. 8 Critical speeds and modal shapes of exciter (case 4)

CONCLUSION

This paper analyzes the reason why the exciter which had been balanced in BOS had to be balanced in field, the exciter with three supporting bearings in field had different distribution of critical speeds comparing with that of in BOS, the unbalance condition of exciter was changed in field. Finally five methods for balancing such exciter are presented.

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