Balancing Technique for Turbo Machinery Rotor

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Abstract: - Balancing process carried out in the thermal power station is very complex and complicated. The complete unit is to be cooled down for balancing this takes nearly 10 to 15 days. After cooling the unit is disassembled and the rotor is taken out for which again 10 to 15 days are required for balancing and assembly. Rotor is placed on the balancing machines for balancing which is carried out by Engineers of the testing department. Balancing of a bulky rotor is difficult and it is carried out step by step. After balancing, complete rotor is to be placed in the turbo machine which is a most difficult task as it has to match the all alignment and other conditions properly. The complete process takes period of nearly one and half month for balancing the rotor, so balancing of the rotor is called to be the costly project in the thermal power station. After the balancing procedure is completed, while starting the complete unit various parameters are to be controlled such as steam inlet temperature, pressure, flow of the steam and rpm of the unit to avoid any type of danger. Loss of production of power during the shutdown period is major loss of any power station. Paper details the automatic thermal balancing of turbo machinery rotor using heating coils.

Key-Words: - Balancing, Heating Coil, Rotor, Turbo Machinery, Centrifugal force

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1 Introduction

Experimental simulator is fabricated for implementing balancing technique. Fabricated model consists of two hollow shafts, heating coils, slip ring, carbon brushes, pulley, journal bearing, wooden platform, coupling and motor. In practice a rotor weighting 20 tons or more and rotating at 1500 rpm may be so well balanced that the motion except for sound is just perceptible. The significance of this statement may be appreciated, when it is realized that if the same turbo machinery rotor were out of balance to the extent of one lb at a radius of 4 feet. In other words, if the CG of the rotor were displaced only $1/1000^{th}$ part of an inch from the axis of an rotation, then the periodic force tending to produce vibration would be 3070 lb weight or 1.36 tons. The unbalance of the particular zone is detected. The heating coil opposite to that zone will be heated by supplying suitable amount of current to the heating coils through the slip ring and carbon brushes which create the thermal condition such as temperature rises and deformation. Heating of coil is carried out while running condition produces thermal stresses in that zone. Centrifugal force acting along the rotor in that heated region is so effective that, these forces will reduce the unbalance.

The new balancing method is the result of attempts through current practice towards satisfying the objective of an ideal balancing process. Balancing of the rotor as it spins, does not generate debris, simple, low cost and reliable.

2 Experimental Simulator

Experimental simulator is fabricated for implementing this balancing technique. Fabricated model consists of two hollow shafts, heating coils, slip ring, carbon brushes, pulley, journal bearing, wooden platform, coupling and motor. Heating coils are placed between the gap of two hollow shafts with the help of insulator, mica sheet and layer of asbestos sheets. Heating coils are connected to the end terminals of the slip rings. Slip rings are provided on both ends of the shaft and carbon brushes are holding over the slip rings. Shaft is placed in the journal bearing and connected to the coupling with the provision of bushes, which are provided to the shaft and to rotate through the motor. Pulley is connected to another end for creating the load through the rigid coupling and extension of the shaft.

2.1 Selection of Rotor

Rotor diameter is selected on the basis of available size of slip rings in the market. Minimum bore diameter of the slip ring available in the market is 40 mm, so as per the standard size available, Rotor size is selected.

2.1.1 Calculation of Heat Generation

Heating coils are directly connected between two slip rings. Slip ring available in the market as per the size have a four terminal, so four heating coils are available (four zones are formed). Two ends of a heating coil are attached to two terminals of two slip rings. To avoid direct contact of heating coil with the surface of the rotor insulated sheets and asbestos sheets are wraps axially along the heating coil respectively. In between these heating coils a layer of asbestos sheet is placed for effective heating in that particular zone.

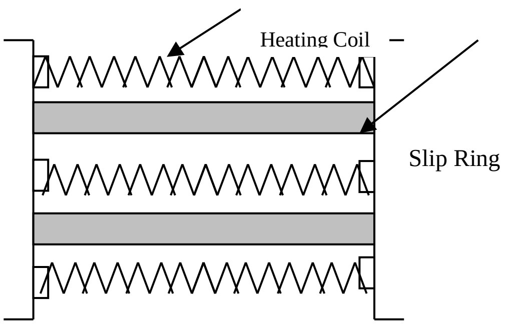


Fig 1: Arrangement for Heating Coil over Inner Pipe with asbestos sheet

Length of the rotor is selected on the basis of taking L/D scale ratio of Turbo machinery rotor of unit No. 3 Thermal Power Station. Propose to work on same type of condition.

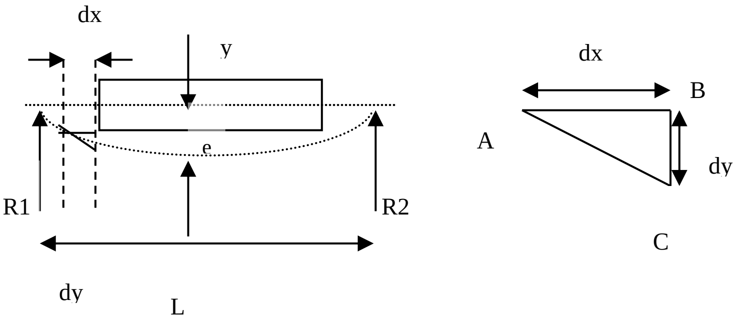
$L / D = 565/68.43 = 8.25$

There is the availability of slip rings in market with 40 mm inner bore therefore diameter of rotor is selected as 40cm, corresponding length of the rotor as per L/D ratio is 34.3 cm.

Finally, length of the rotor is selected considering length of slip ring, journal bearing and clearance as 72.5 cm

2.1.2 Deformation of Rotor

As unbalance increases rotor will start to spin about its mid position as shown in figure. Here y is rotor deflection, taking small element of this rotor for calculating the change in length of rotor.



$$\mathbf{BC/AB = dy/dx}$$

$$AC = \{ AB^2 + BC^2 \}^{1/2}$$
$$= \{ (dx)^2 + [\partial x(\partial y/\partial x)]^2 \}^{1/2}$$
$$= \{(\partial x)^2 + \partial x^2(\partial y/\partial x)^2 \}^{½}$$
$$\mathbf{AC = (\partial x) \{1 + (dy/dx)^2 \}^{1/2}}$$

$$\delta l = \int_{x=L}^{x=0} AC$$

$$\delta l = \int_{x=L}^{x=0} (\partial x) \{1 + (dy/dx)^2 \}^{1/2}$$

$$\delta l = \int_{x=L}^{x=0} \{1 + (dy/dx)^2 \}^{½} dx$$

where $y = f(x)$

2.1.3 Temperature Effect

Thermal stresses occur due to change in temperature of a body, which results in the change of its dimensions. If the body is unrestrained, no stresses will be developed. But if it is restrained, a compressive stress will be induced which is given by delta.

Delta is function of coefficient of linear expansion is α mm/mm ^{o} c and the change of length over the length L is δl.

$\Delta T = \delta l / \alpha * L$

2.1.4 Heat Flow Equation

A hollow pipe with a thermal conductivity k, inner pipe radius r_1 is held at temperature t_1 and outer pipe radius r_2 is held at temperature t_2. Electrical energy is dissipated with the pipe at the q_g per unit volume.

The appropriate form of heat flow equation is,

$d^2t / dr^2 + 1/r\ dt/dr + q_g / k = 0$

Or $d/dr\{r dt/dr\} = - r\{q_g / k\}$

Upon integration

$dt/dr = - r\{q_g / 2k\} + c_1/r$ ….. eq (1)

Another integration gives the general solution for temperature distribution

$t = - r^2\{q_g / 4k\} + c_1 \log_e r + c_2$ …… eq. (2)

The constant of integration is determined from the relevant boundary conditions are:

1. $r = r_1$, the pipe region is perfectly insulated and heat flow is zero
2. $r = r_2$ at $t = t_2$

From Fourier's law $Q = -kA\ dt/dr$, and accordingly the temperature derivative must be zero at $r = r_1$. Hence using expression (1)

$c_1 = (q_g / 2k)\ r_1^2$

Applying the boundary condition $r = r_2$ at $t = t_2$ to expression (2)

$c_2 = t_2 + r_2^2\{q_g / 4k\} - (q_g / 2k)\ r_1^2 \log_e r_2$

$t = t_2 + (q_g / 2k)\ r_1^2 \log_e r/ r_2 + (r_2^2 - r^2)\{q_g / 4k\}$

$t_{max} - t_2 = (q_g / 2k)\ r_1^2 \log_e r/ r_2 + (r_2^2 - r^2)\{q_g / 4k\}$

$\Delta T = (q_g / 2k)\ r_1^2 \log_e r/ r_2 + (r_2^2 - r^2)\{q_g / 4k\}$

$\Delta T = (q_g / 2k)\ \{ r_1^2 \log_e r/ r_2 + (r_2^2 - r^2)/2\}$

Inserting the appropriate values calculate q_g
Therefore, Heat generated q_g is in w/m^3
Total volumetric heat generation:

$Qg = q_g \times$ Area of hallow pipe

In term of electrical quantities,
Heat generated = $I^2 \times R$
Hence the maximum allowable current can be calculated to thermally balance the rotor.

2.2 Analysis of Coil

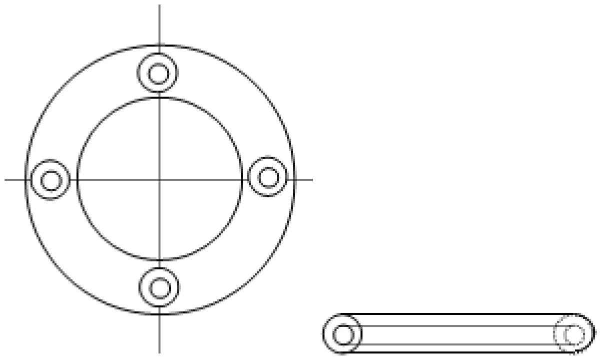


Fig 2. Rotor pipe with heat coil

Outer shaft outer diameter = 87 mm
Outer shaft inner diameter = 82 mm
Inner shaft outer diameter = 38.6 mm
Inner shaft inner diameter = 35.6 mm
Heating coil diameter = 10 mm
Capacity of heating coil = 2000w
Length of heating coil = 45 cm
Thickness of insulation = 21 mm
Thermal conductivity of the shaft material = 45 w/mk
Thermal conductivity of insulation = 0.17 w/mk
Heating coil gap = inner radius of outer shaft – outer radius of inner shaft

= 41 – 19.3 = 21.7 mm

Insulation thickness = heating coil gap – heating coil diameter

= 21.7 – 10 = 11.7 mm

Insulation provided below and above the heating coil diameter = 5.85 mm
Inner radius of heating coil, r1 = 5 mm
Radius of heating coil with insulation, r2 = 10.85 mm
Radius of outer shaft, r3 = 13.35 mm

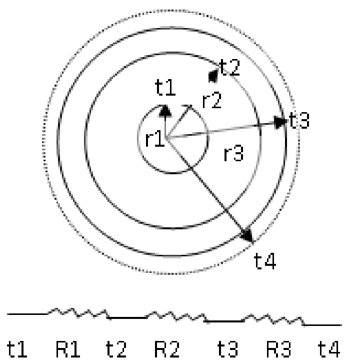


Fig 3. Rotor with various radius

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Taking heat transfer coefficient from the outer surface of the insulation to the surrounding = 10 w/m^2k

Heat transfer , Q = (t1 – t4)/ (R1+R2+R3)

Where

$R1 = \log_e r2/r1 \ / (2\prod kl)$

$R2 = \log_e r3/r2 \ / (2\prod kl)$

$R3 = 1 \ / (2\prod r3lh)$

$t1- t4 = \Delta T = \delta l / \alpha * L$

substituting the above value, Q is calculated in Watt under steady state all the heat produced on account of current flow must be transferred to the surrounding. Therefore,

Heat generated per unit volume, $qg = Q / (\prod r^2 l)$

In terms of electric quantities, current density I and electrical conductivity ke,

Heat generated per unit volume = i^2/ke

Current required raising the temperature,

I = i*A

A = Area of heating coils, m^2

This much amount of current I is to be supplied for rising the temperature and $mr\omega^2$ is the centrifugal force required for reducing the unbalance.

3 Experimental Simulator for Balancing

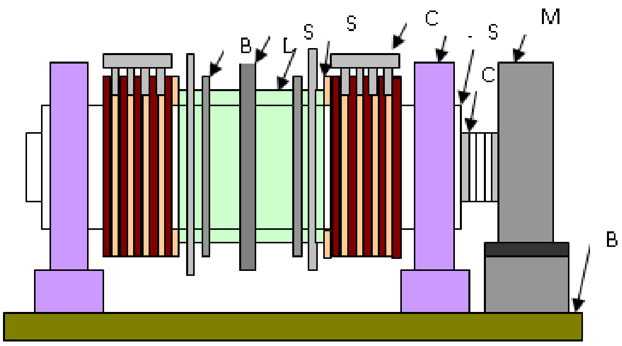

Fig 4: Experimental Simulator for Automatic Thermal Balancing of Turbo Machinery Rotor

Ba = Base of the Model, M = Motor, C = Coupling, S1 = Inner shaft, S2 = Outer shaft, JB = Journal Bearing, CR = Carbon Rod Assembly, S = Slip Ring, D = Circular Disk, B = Blade.

During the balancing, unbalance is detected as per the zone. Correspondingly heating coil opposite to that zone will be activated. Coil will be heated by supplying suitable amount of current to the heating coils through the slip ring and carbon brushes.

Thermal condition is formed such as elevated temperature achieved and controlled amount of incremental deformation is produced. Centrifugal induced stresses are produced in that zone. The centrifugal forces acting over the heated zone are so effective that these forces will reduce the unbalance. A physical balance assembly is schematically shown in Fig 4. Four heating coils are connecting to four terminals to a pair of slip ring, which is on both ends of the rotor. On slip ring, carbon brushes are located on both the ends of the respective slot of the copper strip. Current is supplied to the respective heating coils through the carbon brushes. Heating coils are placed axially over the circumferential 90-degree apart on the rotor. Between two heating coils a layer of asbestos sheets, mica sheets, insulator sheets are placed. So, the heat cannot be transferred over the other zones of heating coils when particular heating coil zone is activated.

4 Testing of Experimental Simulator

This testing is done using the instrument vibroport 41. Connection between photocell, accelerometer pickups and FFT analyzer is the one set of connection. Other set of connection is the connection between heating coils through the switches on the switchboard, ammeter and dimmerstat. Vibroport 41 measures the unbalance reading on bearing1 and bearing 2 in micrometer. Table 1 shows the readings taken on both bearings. Level of unbalance is reducing due to the supply of the current through the dimmerstat. In this case only one heating coils is active were as other are at zero voltage.

Table 1: Reading using Vibroport 41.

Current (Amps)	Bearing1(µm)	Bearing2(µm)
At no voltage	380	341
1	316	330
3	316	320
8.3	304	284
9	289	279

Fig 5: Testing setup of the experimental simulator when current supplied to the heating coils

5 Result and Discussion

The tests performed indicate the level of unbalance decreases as current is supplied to the heating coil. For quick balancing, current supply is to be increase. So as to rises the temperature of the heated portion to reduce the level of unbalance.

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