THE STATIC BALANCING OF TURBINE ROTORS.

The following account of a method for statically balancing rotors may be of interest as affording a ready means of performing this operation with a very satisfactory degree of precision.

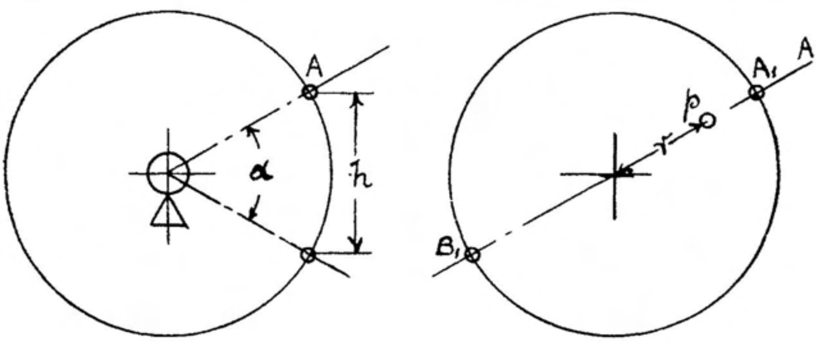
The method was developed in one of H.M. Dockyards with the primary object of balancing the high speed rotors of De Laval turbo generators, which weigh about 2½ cwts. each and have a working speed of 10,000 R.P.M., thus necessitating the most accurate balancing.

Attempts were made initially to obtain a balance by placing the rotor on flat rails, applying an impulse and observing the position at which the rotor came to rest. It was found, however, that even when using curved and hardened steel rails, together with special hard steel stub axles on the rotor, that the minimum out of balance weight that could be detected was 120 grains at the periphery. On service, however, these rotors developed vibration when the out of balance but slightly exceeded the minimum figure just quoted, and thus it became essential to adopt some more accurate method.

It was therefore decided to test the method of balancing which is the subject of this paper: the origin of this method is somewhat obscure but of its accuracy, as developed by the Dockyard in question, there can be no doubt, it having been found possible to reduce the unbalance to a maximum of 5 grains at the periphery of the De Laval rotors referred to above.

Theory of Oscillation Method of Balancing.—Consider a perfectly balanced rotor, supported on two knife edges by its axles, a weight P being attached to the disc at A. If rotation is permitted under the action of the weight, then when A has fallen a distance of "h" the disc will have attained an angular velocity "w" such that $\frac{1}{2} Iw^2 = Ph$.

The complete travel of the weight, a circular arc, will thus be accomplished in a time "t" which is inversely proportional to "w," that is $t^2 \propto \dfrac{1}{P}$



Turning now to the case of a rotor which is out of balance by an amount "p" at radius "r" in position A, if a weight "P" is added at A^1 and B^1 (in conjunction and in opposition to p) in turn and the respective times of oscillation noted, say, t_1 and t_2, then approximately

$$t_1^2 = \frac{K}{P + p} \text{ and } t_2^2 = \frac{K}{P - p}$$

$$\text{or } \frac{P + p}{P - p} = \frac{t_2^2}{t_1^2} = R \text{ (say)}$$

$$\text{and } p = P\,\frac{(R - 1)}{R + 1} = P\,\frac{(t_1 + t_2)\,(t_2 - t_1)}{t_1^2 + t_2^2}$$

Obviously then the foregoing principle may be applied to obtain the value and angular position of the out of balance of any rotor, the actual method adopted being as follows :—

Rotors of small mass are, where possible, fitted with temporary stub axles of hardened steel and the oscillation test is carried out on hardened rails with convex surfaces : larger rotors are, however, balanced on flat topped rails of sufficient width to avoid indentation of the rotor shafts. In all cases the rails are carefully levelled by spirit level or inclinometer and are thoroughly freed from dust and grease.

Eight equidistant spots are then marked off on the largest convenient periphery of the rotor, while a scribing block is arranged with its pointer on a level with the axis of the rotor shaft and adjacent to the marked part of the periphery.

A weight P is then attached at (say) position 1 and the time of a complete oscillation is taken, observing the interval between successive passages of the same spot on the rotor past the scriber point. The test is made by attaching the weight to each of the various marked positions, 1 to 8, in turn, and noting the time of oscillation in each case : the oscillation test is made in both the clockwise and counter clockwise directions for each point, being repeated twice, thus giving 4 readings, the mean of which is recorded. A convenient form for recording purposes is indicated by the following Table :—

Test of Rotor for De Laval Turbo Generator.

Weight at Position.	Time of Oscillation—Seconds.									
	1st reading.		2nd reading.		1st reading.		2nd reading.		Means.	
	Initial.	Final.	Initial.	Final.	Initial.	Final.	Initial.	Final.	Initial.	Final.
1	37·8	35·4	37·4	35·2	36·8	34·8	36·8	35·2	37·2	35·15
2	36·0	35·2	36·2	35·4	34·2	35·0	34·4	35·0	35·2	35·15
3	35·0	35·2	35·0	35·0	33·4	35·0	33·6	35·0	34·25	35·05
4	33·4	35·0	33·8	35·2	33·2	35·2	33·4	35·2	33·45	35·15
5	33·6	35·6	33·4	35·8	33·0	35·2	33·2	35·4	33·3	35·5
6	33·4	35·6	33·4	35·4	34·4	35·8	34·6	35·8	33·95	35·65
7	35·2	34·8	35·4	35·0	36·8	35·4	36·6	35·6	36·0	35·2
8	37·6	35·2	37·4	34·8	37·2	35·4	37·4	35·4	37·4	35·2

$W = 2 \cdot 5$ cwts.
$P = 660$ grains.
$r = 15 \cdot 7$ inches.

	Initial.	*Final.*
out of balance w =	$76 \cdot 2$ grains.	$11 \cdot 2$ grains.
t (max.) =	$37 \cdot 4$ seconds.	$35 \cdot 65$ seconds.
t (min.) =	$33 \cdot 3$ seconds.	$35 \cdot 05$ seconds.
Position of minimum ordinate	No. 5.	No. 3.
,, ,, maximum ,,	No. 8.	No. 6.

The mean values are then plotted on a base of length of periphery, as indicated on Fig. 1, thus enabling the maximum and minimum values to be read off: obviously these limiting values correspond to the positions when P is acting respectively in conjunction and in opposition to the "out-of-balance" weight, the angular position of which can therefore be located with some precision.

The amount of out of balance, W, is given by

$$W = PX \frac{(t \text{ max.} - t \text{ min.})\ (t \text{ max.} + t \text{ min.})}{t \text{ max.}^2 + t \text{ min.}^2}$$

This weight is temporarily attached at the position recorded for t max. and a further oscillation test is carried out, the whole process being repeated till (t max. $-$ t min.) is about $\frac{3}{4}$ second, which is about the limit of accuracy obtainable. The correction thus found is carried into effect by adding or removing weights at a suitable position and radius on the rotor, a final oscillation test being carried out to test the accuracy of the work.

The weight P can have any value exceeding that of the out of balance, but it is preferable to use rather a heavy weight as thereby the resistances to motion are rendered of less importance. On the other hand, P must not be too great or the resulting curve becomes very flat, making location of the position of p a matter of some difficulty. A convenient compromise may be effected by selecting a value for P such that the time of oscillation is about 40 seconds, but if on the initial test the rotor shows an inclination to stop under these conditions, then the preliminary balancing should be carried out with a reduced period: in this event, however, it is desirable to revert to a 40-second period for the final test.

This method of static balancing is undoubtedly superior to the usual methods employed for the purpose, especially in unskilled hands, but it is, of course, open to the objection, common to all static balancing, that the correction of static unbalance may introduce severe dynamic unbalance; this objection is, however, greatly minimised in the case of single disc rotors mounted midway between their supporting bearings. In dealing with multiwheel rotors it is desirable to balance the shaft with only one wheel in place, repeating the operation as each wheel is added, in each case the corrections being applied to the wheel last fitted.

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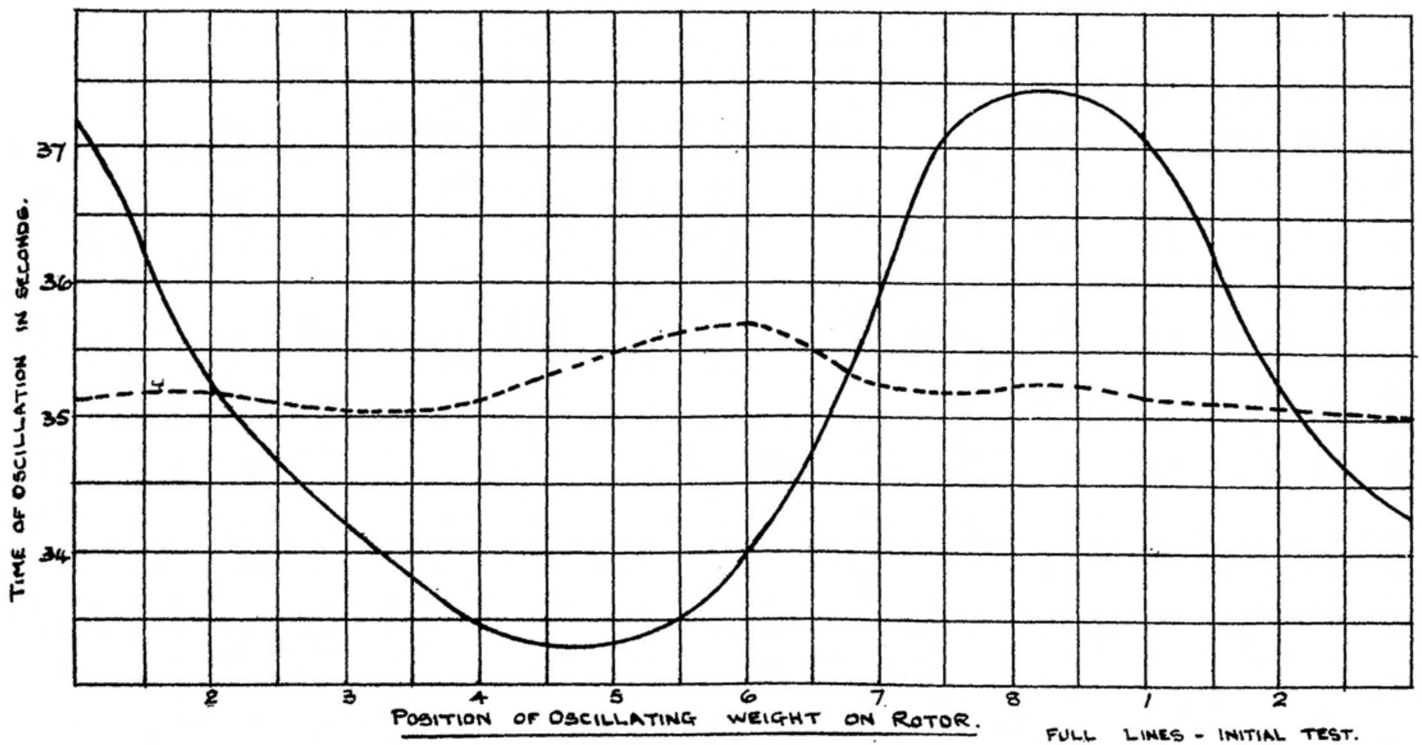

BALANCING OF ROTORS.
FIGURE. 1.

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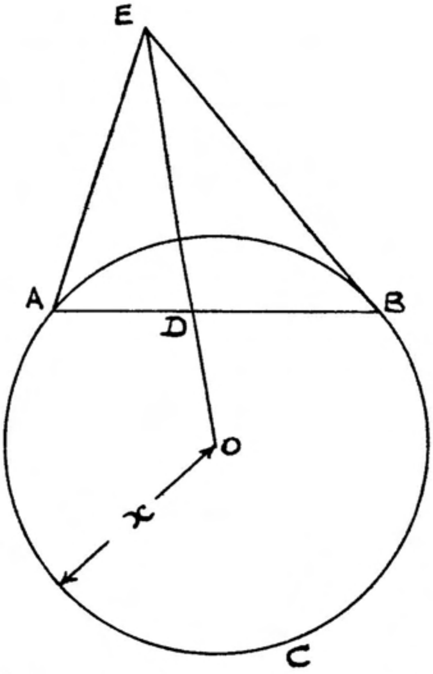
This step-by-step method, while not ensuring a good dynamic balance, is calculated to be less unsatisfactory in this respect than the more simple procedure of balancing the rotor as a whole in a single operation. In conclusion, it is well to note that no operation involving static balancing alone can be considered as adequately replacing the use of an efficient dynamic balancing machine, although the results given by methods such as that just described may be sufficiently accurate for practical purposes in cases where the revolving masses are sensibly uniplanar.

NOTE.—*Combination of Balance Weights.*—During the operation of balancing it frequently becomes necessary to replace two trial weights by a single weight with the same resultant effect: this may conveniently be effected as follows :—



It is desired to replace two weights W_1 and W_2 at radius x by a single weight W on a radius y.

Draw circle ABC of radius x, the points A and B representing the relative positions of W_1 and W_2. Join AB and mark off $AD = \left(\frac{W_2}{W_1 + W_2}\right) AB$. Join D to centre, O, of the circle ABC. Produce OD to E such that $OE = y$, the radius at which the single weight is to be added.

Measure AE and AB and mark these off on the rotor in order to locate E, the correct position where the combined balance weight should be fitted. The value of the single weight is given by :—

$$W = \frac{OD}{OE} (W_1 + W_2).$$