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PRECISION LASER SHAFT ALIGNMENT AND ROLLING BEARINGS OF ROTATING MACHINES HIGH-FREQUENCY VIBRATION.

D. Litvinov
J. Rudzitis
Riga Technical University,
1 Kalku Street, PDP, LV-1658, Riga
Latvia

ABSTRACT
In world industry one of leading places on application occupies the rotating machines. It can be: different gearboxes, pumps, electric motors, compressors and etc. One of most essential nodes of these machines is rolling bearing. So it is very important to look after rolling bearings condition, by the rolling bearing high-frequency vibration (vibration with frequency over 20 kHz) monitoring without contact, and also it is necessary to conduct measurements on precision laser shaft alignment of rotating aggregates by the laser shaft alignment systems.
A necessity in precision laser shaft alignment (it is regulation of shafts offset displacement in margins from 0,01 to 0,001 mm, and angular deviation with exactness from 0,01mm/100mm to 0,001mm/100 mm) arises up not only at high-speed aggregates (with the revolution numbers over 3000 rpm) but also at low-speed aggregates.
Keywords: frequency, exactness, monitoring

1. INTRODUCTION

Most industrial enterprises have a base of rotation machinery. Practically all of them have bearings and greater parts from these bearings are rolling bearings. These bearings constitute by itself one of important parts of rotor equipment and after which it is necessary to conduct a permanent supervision. Looking after the vibration states of bearings allow to reveal defects in them on the initial development stage, and also to make the bearing's state estimation and give the prediction of working capacity. On rolling bearings defects origins influences different factors:

1. Low-quality greasing, its failing or complete missing;
2. Low-quality bearings installation;
3. Bearings production defects;
4. Wrong equipment maintenance;
5. Out-of-balance of equipment rotating elements;
6. Low-quality shaft alignment or its complete missing.

We will drop the first five from six above-mentioned factors and will consider the sixth factor. As statistics [2] assert about 50% percents of industrial equipment fails are shaft alignment problems. There is a reaction torque of misaligning shafts, which result is overload of bearings.

Historically, shaft alignment allowances were determined by structural specifications of couplings producer. Main function of flexible coupling – to take in the small sizes of misalignment which remaining after rough shaft alignment (it means, shaft alignment by straightedge and gauge-feeler). It is necessary to underline that allowances, offered by coupling manufacturers, provide reliable service,

in supposition that a flexible element will fail before, than the important element of machine. But most likely, a coupling will not damage under loadings, whereas rolling bearings certainly will break

in these conditions. Normally, rotor equipment bearings have very small internal gaps and sensitive to such harmonic forces more than to the permanent shock loads.
For an example, excessive shaft misalignment more than 0,05 mm for a machine, working on 3600 rpm , under normal working conditions can create large forces which are enclosed directly to machine bearings and cause excessive stress and wear of bearings.
One of main reasons of multiplying this force is bad shaft alignment or its complete missing. Even at shaft alignment availability and it carried out under the generally accepted norms, influencing of the operating force on bearings remains. It is justified, that under these rates an angular deviation of shafts is in limits from 0,01 to 0,1 mm/100mm depending on rotation speed, and shafts offset values are in limits from 0,01 to 0,13 mm depending on rotation speed of shafts [1]. However most of modern laser shaft alignment systems allow conducting high-precision shaft alignment to within 0,001 mm. It is necessary tend to conduct shaft alignment works with such precision exactly.
Thus such precision is needed not only for high-speed aggregates ($n \geq 3000$ rpm), but also for the low-speed aggregates. Work time, which an alignment specialist will spend during a precision shaft alignment with usury, will be repaid with interest by reliable and long-term work of equipment, and also high quality of final products.
Another positive aspect of high-precision shaft alignment is that after its realization it is considerably easier to carry out vibration monitoring and diagnostics through the modern systems in a high-frequency range [4]. Thus high-precision shaft alignment and rotating aggregates high-frequency vibration control is two interconnected procedures. The regular conducting of these procedures multiplies lifetime of bearings considerably.

2. STATEMENT OF PROBLEM.

The experiment expounded further shows close connection between shaft alignment and vibration of rotating aggregates. A vibration during this experiment is measured as vibration acceleration.
For the experiment has selected the pump aggregate, which consists of: cantilever, horizontal, double-stage pump; induction motor (n = 3000 rpm); gear coupling.
The purpose of my research is: establishment of due regularities between such factors as shaft offset, angular deviation of shafts and bolts strap force moment of equipment fastening to foundation by complete factorial conducting which influences on the vibration origin, and that results in equipment breakage. During the experiment as the optimization parameter (response function) is the vibration acceleration value $(\hat{y})$ and by factors, influencing on this parameter will be:

- Shaft offset value (Q);
- Angular deviation of shafts value (E);
- Bolt strap force moment of equipment fastening value (P)

3. EXPERIMENT CONDUCTING.

A complete factorial is an experiment, realizing all possible non-recurrent levels combinations of independent factors; each of them is varied at two levels. Number of these combinations: $N = 2^k$.
For a three-factor task selective equation of regression looks like [3]:

$$\tilde{y} = \hat{M}\{y\} = b_0 + \sum_{i=1}^{3} b_i x_i + \sum_{i,j} b_{ij} x_i x_j + b_{123} x_1 x_2 x_3 \qquad (1)$$

A complete factorial is given by possibility to find the separate coefficients estimations.
In *Table 1* columns x_1 ; x_2 ; x_3 form planning array. The terms of experiments concern directly by them.

Table 1.Three factors extended matrix for planning

Plan point Nr.	x_0	x_1	x_2	x_3	x_1x_2	x_1x_3	x_2x_3	$x_1x_2x_3$	Lines code designation	Optimization parameter
1.	+	-	-	-	+	+	+	-	(1)	y_1
2.	+	+	-	-	-	-	+	+	a	y_2
3.	+	-	+	-	-	+	-	+	b	y_3
4.	+	+	+	-	+	-	-	-	ab	y_4
5.	+	-	-	+	+	-	-	+	c	y_5
6.	+	+	-	+	-	+	-	-	ac	y_6
7.	+	-	+	+	-	-	+	-	bc	y_7
8.	+	+	+	+	+	+	+	+	abc	y_8

We will make basic levels factors selection, close to applied in practice. Varying intervals coming from the real vibration limits. Factor values are given in *Table 2*.

Table 2.Levels of factors and varying intervals

Levels of factors	**Designation**	**Q (mm)**	**E (mm/100mm)**	**P (Nm)**
		$\tilde{x}_1$	$\tilde{x}_2$	$\tilde{x}_3$
Main	0	0,007	0,010	350
Varying interval	$\Delta\tilde{x}_i$	0,005	0,008	50
Top	+1	0,012	0,018	400
Low	-1	0,002	0,002	300

In every point of factor space test repeated oneself for 3 times. Each time, during the test, when one of three parameters was regulated in accordance with the matrix of experiment, the other two parameters were set on a main level (*Table 2*).

3.1. Mathematical model of the object.

The purpose of complete factorial conducting is a description of the studied object as equation (1). Further made the object mathematical model drafting as connection equation of output parameter $\hat{y}$ and variables x_i and where included maximally significant parameters:

$$\hat{y} = 7{,}63 + 1{,}53x_1 + 1{,}11x_2 + 1{,}20x_1x_3 \qquad (2)$$

As a result: $$\hat{y} = 4{,}99 - 26{,}7 \cdot Q + 6{,}94 \cdot E - 0{,}01 \cdot P + 0{,}12 \cdot Q \cdot P \qquad (3)$$

Further we will make factors real values substitution, and within chosen before limits of the varying intervals in equation (3), generalize this information in *Table 3* and on their foundation build the graphs of dependences (*Figure 1 and Figure 2*).

Table 3. Table of data comparison

Q (mm)	E $(mm/100\,mm)$	P $(N \cdot m)$	$\hat{y}$ (mm/sek)
0,002	0,002	400	0,155
0,003	0,003	390	0,190
0,004	0,004	380	0,222
0,005	0,005	370	0,252
0,006	0,006	360	0,280
0,007	0,007	350	0,305
0,008	0,008	340	0,327
0,009	0,010	330	0,355
0,010	0,012	320	0,379
0,011	0,015	310	0,409
0,012	0,018	300	0,436

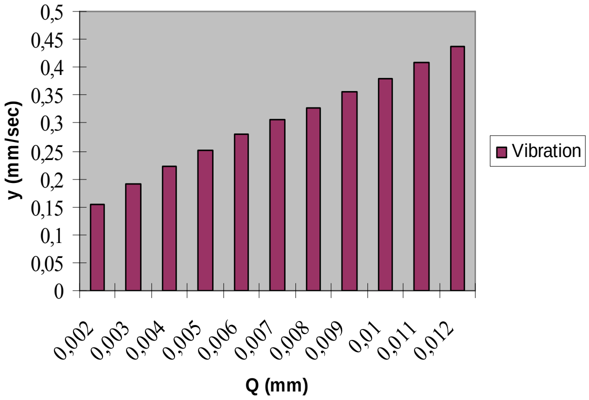

Figure 1. Dependence graph $\hat{y}$ from Q

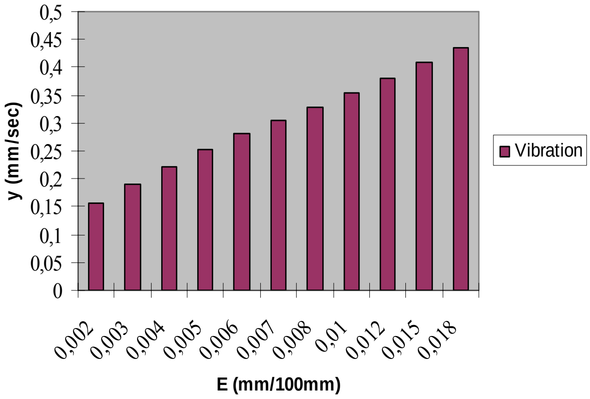

Figure 2. Dependence graph $\hat{y}$ from E

4. CONCLUSIONS

The conducted experiment proves that shaft alignment rejections even in insignificant margins gives in a result vibration level increment at first in a high-frequency, and then transition in middle-frequency and then in low-frequency range. It gives rise to the considerable overload of bearings and as a result rapid breakage.

Exists the opinion, that high-precision shaft alignment (with exactness from 0,01mm/100mm to 0,001mm/100 mm) is needed only for high-speed aggregates, and also for aggregates with inflexible coupling, but the conducted experiment refutes it. It could explain that bearings of both types of aggregates (high-speed and low-speed) have taken the identical loading on an absolute value. A difference lies only in an excitation loading frequency. In any case lifetime duration of bearings, in misalignment case will be considerably less. Thus bearings lifetime will be the inversely to misalignment size, multiplied on machine working shaft rotation frequency.

5. REFERENCES

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