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Influence of foundation stiffness on vibrations of rotor systems

P. Mažeika, J. Grigonienė, A. Senulis

Klaipeda University, Bijunu 17, LT-91225
E-mail: pranasmazeika@centras.lt
jurgita.grigoniene@ku.lt,
audriussenulis@yahoo.com

Abstract

In this paper mechanical system containing four horizontal blowers with separate frame each is analyzed. The system is fixed on one general foundation. The high level of vibrations is dominating during the work of the system. The results of experimental investigation of mechanical system are represented here. The finite element model of the operation investigated system gives possibility to investigate natural frequencies. The reasons of high level vibrations were identified by comparing the results of experimental data and theoretical calculations. The concept of vibrations reduction based on the results of this investigation was proposed as well.
Key words: vibrations, diagnostics, natural frequencies, finite element method, blower.

1. Introduction

Among the methods which make it possible to establish a diagnosis of the operating condition of a mechanism, the vibratory techniques seem very promising and are booming. The research technology of vibrations of rotor machines enables precise identification of the evolving machine defects and enables protecting these machines from unexpected faults and breakdowns. Also this technology helps with the identification of the vibrations sources of rotor systems and engineering and installation mistakes.

There are a lot of works devoted to this problem.

The development of a test bench to characterize vibration sources which apply unspecified excitations on a receiving structure was described. The approach is based on characterizations of a component mounted on different plates for classification with respect to the mobility of the receiving structures [1].

The threshold according to the level of the uncertainties of the measurements was defined as well [2].

In the paper [3] two methods to improve force identification are presented. The first is based on improving the conditioning of the system FRF matrix by a proper selection of the measurement positions. An expression for the covariance matrix representing the uncertainty on the force estimate is defined. Then the response selection algorithm, which is both systematic and effective, is derived. The basic strategy in selecting the response positions is to let the smallest singular value be as large as possible. The second method is based on modification of the structure by attaching a dynamic damper at a suitable location to minimize the ill-conditional nature of the FRF matrix especially near a resonance frequency [3].

In practice, the vibration measurements made by sensors come from a mixture of vibration sources corresponding to different machine components. Thus, it becomes difficult to conduct state interpretation for each individual component. This article proposes to link modal analysis and stability. This link allows us to reduce the number of sensors and to avoid regularization methods [4].

The diagnosis and monitoring of each component require the determination of the contribution of each source in the signal collected. The objective of this work is to use and optimize the techniques applied to the inverse problems with the aim of quantifying the contribution of each source in the obtained mixture, more particularly, the sources which are characteristic of a damaged element. The paper proposes a methodology, based on the reconstruction of the sources. Thus, the methodology ensures the detection and the localization of a defect of the component by the optimization of the position of a limited number of sensors [5].

The purpose of this paper is to analyze the reasons of high level vibrations of four centrifugal blowers and develop the concept of the vibration intensity reduction.

2. Description of blowers

The four centrifugal blowers are used for n cooling in the food industry. The kinematics and technical parameters of the blowers are identical:

- power of the electrical motor – 30 kW,
- nominal speed of the rotor – 2958 rpm/min (the control of the rotation of rotor is implemented by using frequency converters).

The blower consists of the electrical motor with the rack fix working wheel and the frame (Fig. 1). The dampers are mounted between the frame and the foundation (on the second floor) to reduce the intensity of blower's vibrations.

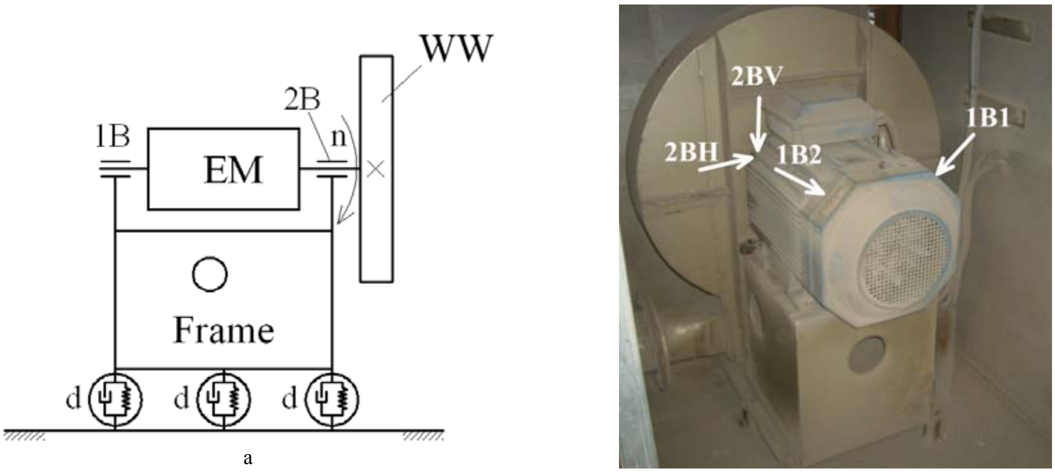
There was a significant level of vibrations detected from the start of exploitation of the blowers in natural industrial conditions, which had a negative influence on health of nearby employees working on the first and the second floor of the building.

3. Dynamics of blower's rotating system

Investigation of mechanical vibrations of the four working blowers' rotation systems was made in the natural exploitation conditions. The investigation was done using the vibration signal analyzer A4300-VA3 (Adash, Czech

Republic) with the vibrations accelerometer (Wilcoxon Research 797, USA). The accelerometer was mounted using magnets on the measuring points. The experimental research was made during the blowers operation at 60-100% load.

The main aim of the experimental research was to measure the excited vibrations velocity values v_{RMS} (10÷1000 Hz) of the blowers, identify the sources of the vibrations and determine the high level vibrations appearance reasons.



a

b

Fig. 1. **The kinematics of blower rotor system (a) and general view of blower (b): 1B and 2B – the first and the second bearings; EM – electromotor; WW – the working wheel; n – rotational direction; d – the dampers; 1B1, 1B2, 2BH and 2BV – the vibration measuring points**

The experimentally measured vibration velocity values v_{RMS} of the rolling bearings of blowers are presented in Table 1. All measured bearing support vibration velocity values v_{RMS} of the blowers, except for the fourth machine, were in D vibration intensity range (by ISO 10816). The maximum measured vibration velocity value v_{RMS} was 16,29 mm/s (for the first machine of the first bearing in a horizontal direction). According to ISO 10816 standard these machines can not be exploited.

Table 1. **Experimental research results of centrifugal blowers**

Measuring direction	Vibrations velocity values v_{RMS} of bearing support, mm/s							
	Blower No.1		Blower No.2		Blower No.3		Blower No.4	
	Load 100 %						Load 60 %	
	1st bearing	2nd bearing	1st bearing	2nd bearing	1st bearing	2nd bearing	1st bearing	2nd bearing
Vertical	8,47	5,24	6,42	7,65	9,44	11,05	2,15	5,71
Horizontal	16,29	3,25	8,65	4,70	6,96	14,95	2,47	2,05

The spectral analysis of bearing vibrations velocity was performed to identify the possible sources of the high level bearing support vibrations of the examined blowers. The spectrum of the horizontal vibrations speed of the first bearing of the first and second blower is presented in Fig.2. Fig. 3 presents the same type of data of the vertical bearing for the third and fourth blowers. These spectrums (till 1 kHz) has a dominating vibration frequencies of the rotor which are nearby synchronous (1X=49÷49,3 Hz) and nearby supersynchronous (2X=98,1÷98,75 Hz, 3X=147÷148,1 Hz, 4X=196 Hz) frequencies. These vibrations emerge due to low stiffness of the foundation and blowers' frame.

Low stiffness of the foundation and frame changes the axis position of the blower rotor, therefore resulting in excitation of additional dynamic forces (dynamic unbalance) at bearing supports and wear of these supports. The forth blower has a relatively lower vibration level in a bearing supports in comparison with other examined blowers due to the 60% load of the fourth blower.

The more detailed investigation of the reasons of the high level vibration appearance of the first three blowers was implemented by measuring and analyzing vibrations of blowers' frames. The measurements of the frame vibrations velocity values v_{RMS} were taken from 9 points of the frame and presented in Fig. 4. The measurement was performed with the same equipment as mentioned above. The results of these measurements are presented in Table 2. The experimental data revealed that the biggest vibrations velocity values v_{RMS} of the measured frames are at 5A (the 1st blower frame) and 8A (the 2^{nd} blower frame) measurement points. The vibration velocity spectrum of the 3^{rd} blower frame measurement point 8A is presented in Fig. 5a and the general view of the measurement point 5A – in Fig. 5b.

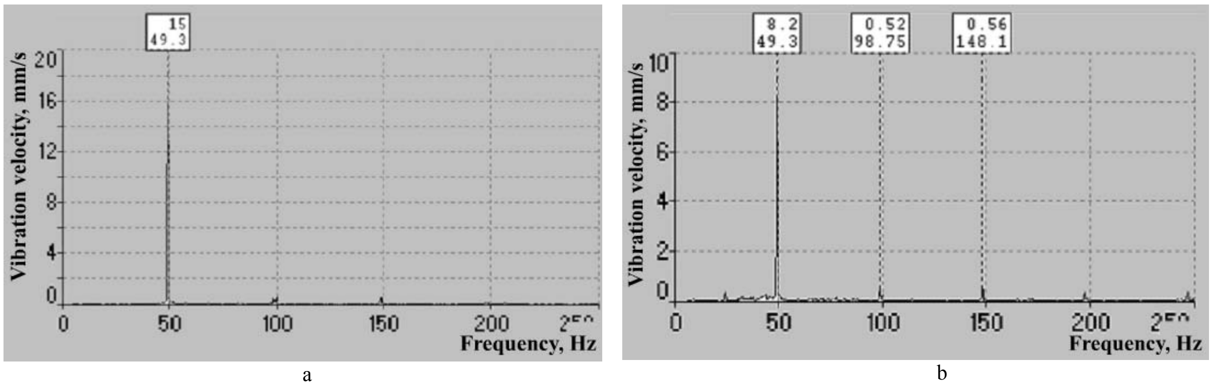


Fig. 2. **The horizontal vibration velocity spectrum of the first and second blower (a) and (b) respectively of the first bearing**

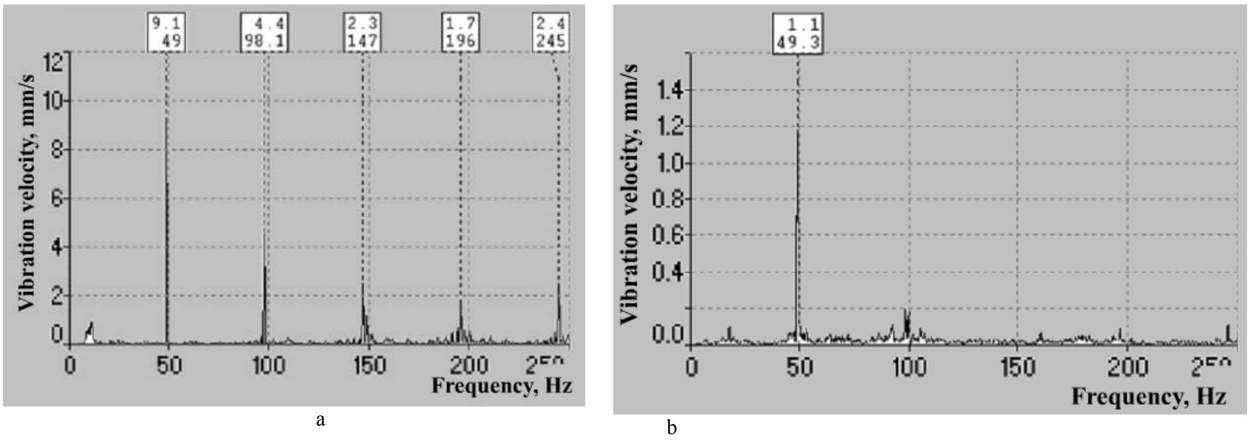


Fig. 3. **Horizontal vibration velocity spectrum of the third and fourth blower (a) and (b) respectively of the second bearing**

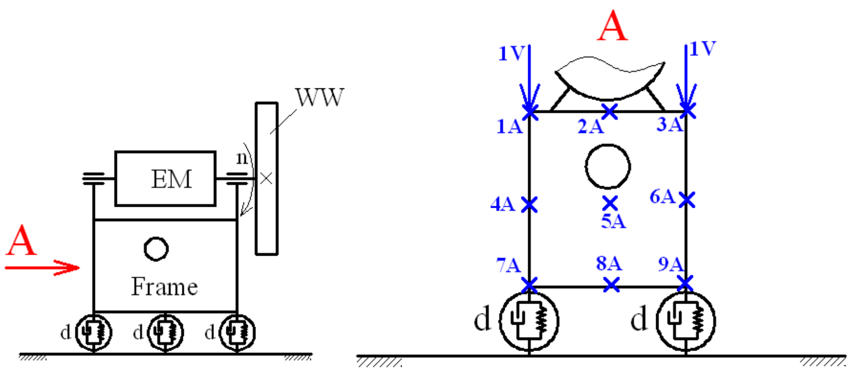


Fig. 4. **The scheme of the vibration measurement points of the blower frame: EM – electromotor; WW – working wheel; 1A, 2A, 3A, 4A, 5A, 6A, 7A, 8A and 9A – measurement points in the axial blower direction; 1V and 3V – measurement points in vertical direction**

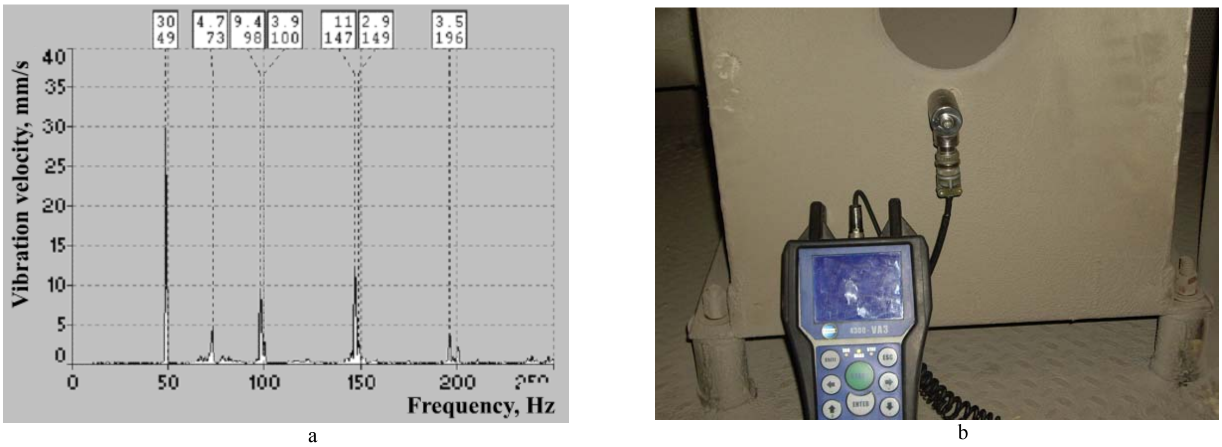


Fig. 5. **Vibration velocity spectrum of the third blower frame at 8A measurement point (a) and vibration measurement general view at point 5A (b)**

Table 2. **Experimental results of centrifugal blowers frame vibrations**

Vibrations velocity values V_{RMS}, mm/s Measurement points										
1st blower frame										
1A	2A	3A	4A	5A	6A	7A	8A	9A	1V	3V
10,90	7,06	6,74	18,40	**54,60**	14,40	23,90	38,90	20,60	9,62	10,10
2nd blower frame										
10,30	3,70	4,73	15,60	25,80	7,34	20,40	**30,70**	13,70	5,05	7,97
3rd blower frame										
4,45	3,24	3,96	15,30	20,50	12,40	13,70	**24,10**	16,10	4,70	7,30

Fig. 5a presents the vibration velocity spectrum of the third blower at 8A measurement point and dominating vibration frequencies of the rotor which are nearby synchronous 49 Hz (30 mm/s) and nearby supersynchronous frequencies vibrations (73 Hz/4,7 mm/s; 98 Hz/9,4 mm/s; 100 Hz/3,9 mm/s; 147 Hz/11 mm/s; 149 Hz/2,9 mm/s; 196 Hz/3,5 mm/s).

During the experimental research of blowers vibrations the loosen damper bolts due to a high level of vibrations were detected.

4. Modeling and simulation of the frame of blower

Theoretical calculations were done for the blower frame resonant frequencies and vibration modes by using the finite element method. The modeling of frames resonant frequencies and vibration modes were performed in two cases:

a) when the damper bolts fixing the frame to the foundation are loosened (dampers do not reduce vibrations of blowers) and the foundation is limp;

b) the frame is stiffly fixed to the foundation.

The theoretical calculations showed that in the first case the first resonant frequency is 36 Hz, the second frequency – 73 Hz and in the second case the first resonant frequency is 73 Hz. The resonant vibration modes of the frame are presented in Fig. 6 and 7.

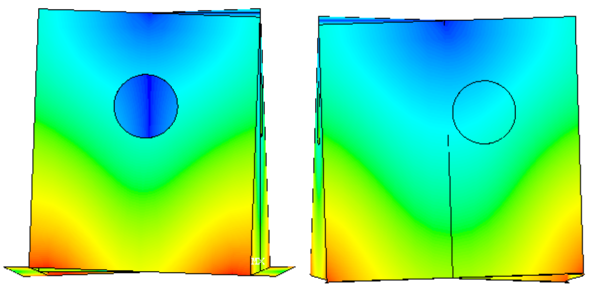


Fig. 6. **The first vibration mode of the blower frame (36 Hz) in the case of loosened rubber dampers bolts and limp foundation**

According to the investigation results the conception of vibration reduction of the blower bearing supports is proposed (Fig. 8).

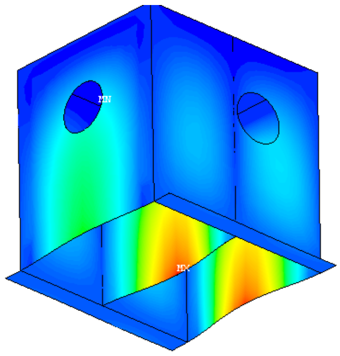


Fig. 7. **The second vibration mode of the blower frame (73 Hz) in the case of loosened rubber dampers bolts and limp foundation; the first vibration mode of the blower frame (73 Hz) in the case of dampers reducing the blower vibrations and stiff foundation.**

5. Conclusions

1. The experimental and theoretical investigation of four identical blowers was accomplished to identify the reasons of high level vibration intensity of the blowers.
2. The vibration velocity spectral analysis was used to identify the sources of vibrations of blower bearing supports and the finite element method was used to investigate theoretically resonant frequencies and vibration modes of the blower frame.
3. Theoretical calculations showed that in the case of loosened damper bolts and limp foundation the first resonant frequency of blower frame is equal to 36 Hz, the second frequency – 73 Hz. Such exploitation of the blowers when rotation frequency of the electrical motor may vary till 50 Hz is dangerous to the machine, because it is operating near the first resonant frequency. In the case when the frame is stiffly fixed to the stiff foundation the first resonant frequency reaches 73 Hz and is bigger than the forced vibration frequency.
4. The measurement results of the vibrations velocity values v_{RMS} of the blower frame and the spectral analysis of the measuring points and the theoretical analysis enabled to identify blower's high level vibration appearance reasons. According to the investigation results the concept of vibration reduction of the blower bearing supports is proposed.

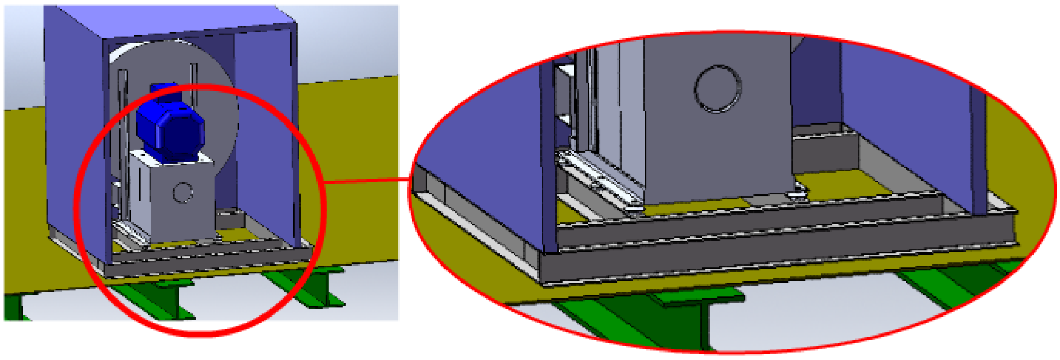


Fig. 8. **The concept of vibration reduction of the blower bearing supports**

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Pagrindo nejudamumo poveikis dėl rotoriaus sistemos virpesių

Reziumė

Buvo tiriamos mechaninės sistemos su keturiais horizontaliais atskiro rėmo pūstuvais. Aukšto lygio vibracija yra ilgiausia darbo sistemos metu. Pristatyti eksperimentinių tyrimų rezultatai ir mechaninė sistema. Naudotas baigtinių elementų modelis. Ištirtos sistemos dažnių galimybės. Nustatytos aukšto lygio vibracijos poveikio priežastys ir palygintos su eksperimentiniais duomenimis ir teorinių skaičiavimų rezultatais. Pasiūlyta, kaip sumažinti vibraciją remiantis rezultatų tyrimo koncepcija. Teoriniai skaičiavimai parodė pūstuvų poveikį vibracijai ir kartu įtaką eksperimentiniams matavimo rezultatams. Pagal tyrimų rezultatus parengta koncepcija vibracijai mažinti

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