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Control of vibrations in rotating mechanical elements

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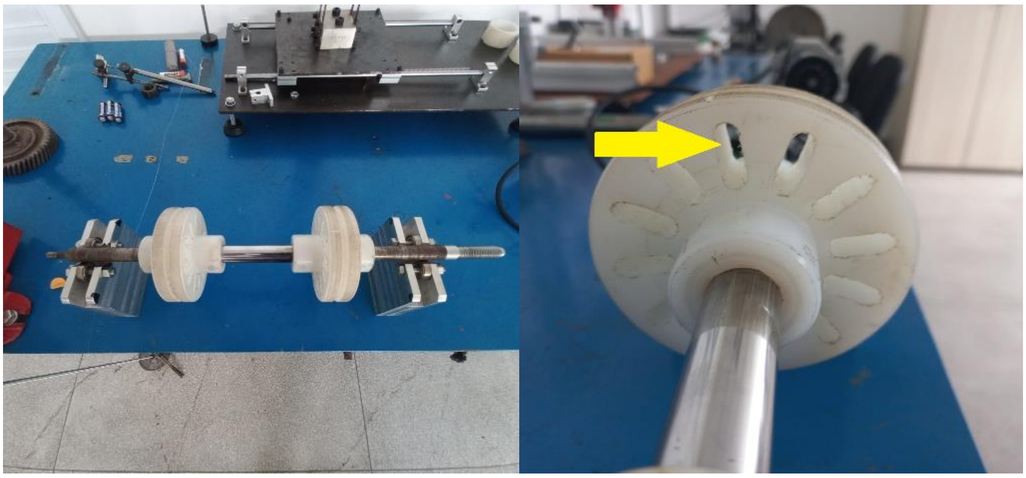
Abstract. We observe commonly disturbances in rotating machinery elements when driven to rotate. These disturbances present themselves as a displacement or trepidation caused by unbalanced masses. The occurrence of balancing depends on eccentricity present, which means that the center of mass and rotating element center are not coincident. The presence of these unbalanced forces - whose magnitude is proportional to the eccentricity, unbalanced mass, and the angular velocity squared - results in severe vibrations and can overload bearings with catastrophic consequences. The main origin of these unbalances is the heterogeneous distribution of the masses around the rotation axis. So, to avoid the overload on bearings and warp the shaft, some control methods such as balancing should be done. In the present work, a dynamic balancing was carried out with a specimen employing a balancer rig. In this experiment, different auxiliary equipment, computer systems, and proprietary software were used. It was possible with this software to automate the measurements, analyze, and obtain a report about balancing results as well. The specimen was made of steel and possessed two mounted nylon disks with oblong holes on them. These oblong holes permitted the fixation of trial masses and correction masses. The degree of balancing quality was determined according to the ISO standard G 6.3; these degrees of balancing guarantee an accuracy level of quality according to the specific application in rotating machines. The balancing on the specimen was correctly applied, and the results have demonstrated that this procedure, balancing, is essential to mitigating excessive vibration and preventing overload in bearings caused by unbalancing in rotating mechanical elements.
Keywords: Unbalancing, Eccentricity, Vibration.

Introduction

It is possible to identify a certain level of vibration in a specimen subjected to constant rotation. The correction of the excitation found in rotors is very important in the design of the machine in question, since an unbalanced rotor can considerably reduce the useful life of the mechanical system, in addition to causing various noises, which can reach resonance, which is considered a big problem because it will take body of the machine to break. Vibrations are caused by unbalanced masses causing the rotation to be irregular. These unbalanced masses cause there to be a gap between the axis of rotation. Vibration control in rotating mechanical elements can take place in two situations: static balancing or dynamic balancing. Static balancing or balancing in a single plane, as the name implies, is when the masses that are generating inertial forces are in or very close to a single plane. Static balancing is equivalent to placing the specimen to rotate around the horizontal axis and observing where the unbalanced masses appear. In a process of placing or removing masses in an iterative process, static balancing is obtained. The aim of this study is to analyze tests carried out at the Laboratory of Vibrations and Acoustics at the Federal University of Viçosa and to develop a balancing method so that the aforementioned impasses are reduce to a minimum percentage. [1] [4]

Methods

The studies were carried out at the Laboratory of Mechanical Vibrations and Acoustics at the Federal University of Viçosa in Brazil, with the test bench, the TEKNIKAO brand balancer, type NK750. With this balancer it is possible to correct static unbalance and dynamic unbalance that can be observed through software. The balancer works through rotation generated by an engine with a belt in friction on the specimen that will be balanced. Balanced, it has two bearings with bearings where the rotor will be supported and, also in these bearings the disturbances of the test specimen will be received where it will be possible to analyze the present eccentricity. To carry out the balancing, it is necessary to adopt a constant low rotation at the beginning of the tests, however, this rotation can be increased to a value close to the working rotation of the mechanical element to be balanced. To begin the analysis of the degree of unbalance of the specimen, it is necessary to consider that the masses that are generating the unbalance cause a change in the position of the center of gravity of the cross section that contains the error, this change in the position of the center is called as above cited eccentricity. To characterize this eccentricity, it is possible to imagine an axis constantly rotating and generating movements within the three-dimensional plane in the X or Z axes, which should not happen if you still consider the three-dimensional plane, since the rotational movement should only happen in the Y axis. used a generic specimen machined properly for studies, analyzes and tests. This specimen has a steel shaft and two nylon discs with slots where it is possible to attach the test masses and balancing masses. Dynamic balancing was adopted since the specimen studied has two discs. Dynamic balancing or balancing in two planes deals with correcting the opposing forces that cause a moment on the shaft. Previously it was only considered that the sum of the forces must be equal to zero. “Dynamic balancing is sometimes called balancing in two planes. This requires that two criteria be satisfied. In the Fig.1 is the specimen test top view while in the Fig.1 the Nylon disk where are fixed the test mass and the balancing masses.



(a) Top view: Rotor with two Nylon disc

(b) Left view: Oblong

Figure 1. Rotor specimen. Piece built by Nylon and steel shaft used to carry out the proceedings of balancing, 2023

Results and discussion

When starting the dynamic balancing experiment, the system was calibrated with data from the generic specimen studied. The requested data were: weight of the test specimen, which is 1270 g, the working rotation of the element, which was considered to be 500 RPM, a usual value for parts such as the one studied, considering the chosen quality grade, which was G 6.3. Some standards determine degrees of quality to be followed so that the specimen is balanced with a minimum value of angular momentum variation, ensuring the good performance of the mechanical equipment where the specimen will be used for work. The quality grades are determined for each type of element to be balanced, following the indications of work that this element will have to fulfill in the future, in addition to considering mainly characteristic points such as weight, size, material, work rotation, and several other factors. [3]

Grades of quality

Below, it is possible to present the quality grades and other elements with their classifications.

G 4000 - Slow marine engine crankshafts;
G 250 - Cylinder fast diesel engine crankshafts;
G 40 - Car wheels; transmission shafts;
G 6.3 - Fans; steering wheels; pump rotors;
G 2.5 - Gas and steam turbines; drive of machine tools;
G 0.4 - High-precision grinding machine spindles, gyroscopes.

Studding theoretic

From Newton's second law [2]:

$$\sum F = m\ddot{x} \qquad (1)$$

The governing equation [5] that describes the unbalanced motion of a mechanical system is given by

$$m\ddot{x} + m_0\ddot{x}_r + kx + c\dot{x} = 0 \qquad (2)$$

where m and m_0 correspond respectively the inertia and unbalanced mass, c is viscous damping, and k is the stiffness constant. In the next step, we use the rotating operation $(w_r,)$ we can apply the particular solution Eq. 3 in the Eq. 2

$$x_r = e \sin(w_r t) \qquad (3)$$

"e" is eccentricity. Before do that and rearranging the terms from Eq. 2 the result is shown in

$$m\ddot{x} + c\dot{x} + kx = m_0 w_r^2 e \sin(w_r t) \qquad (4)$$

The correspondent steady state displacement caused by this unbalanced force F_d is

$$x_r t = x\, sin(w_r t - \theta) \qquad (5)$$

where x is the amplitude and θ represents the angle phase.

$$\frac{mx}{m_0 e} = \frac{r^2}{\sqrt{(1-r^2)^2 + \sqrt{(2\varepsilon r)^2}}} \qquad (6)$$

where $r = \frac{w_r}{w_n}$ is the frequency ratio, is the damping ratio, w_0 is the fundamental frequency, and the angle phase θ can be calculated by

$$\theta = tan^{-1}\{\frac{2\varepsilon}{1-r^2}\} \qquad (7)$$

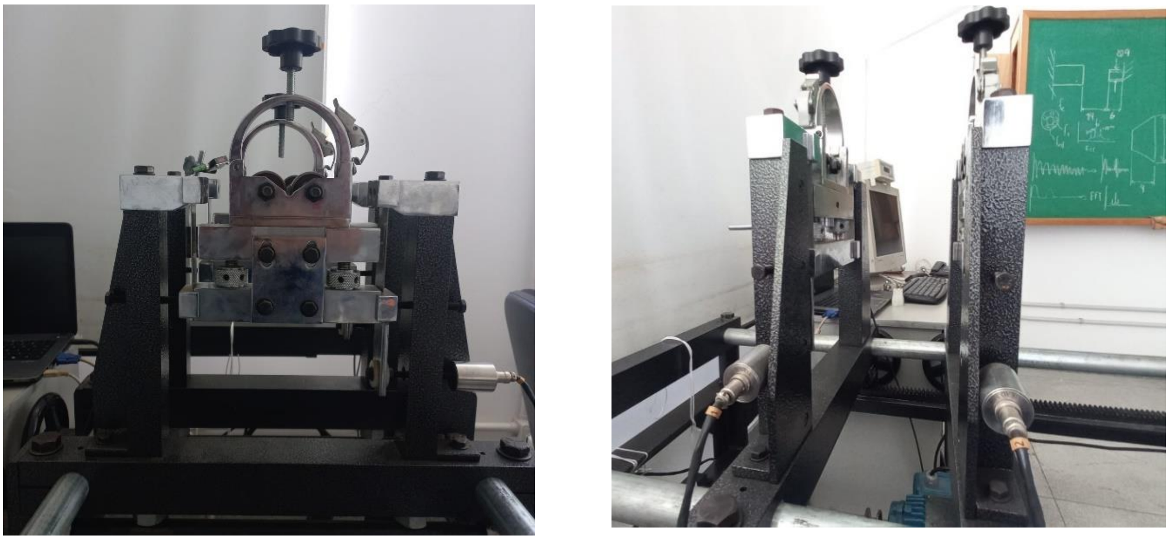
These calculi integrate the concept under the balancing theory which is used in the fundamentals applied in the balancing machine as it shown in Fig. 2.

Unbalance

After reading the vectors, the system showed the degree of unbalance and from that moment on, the test masses were removed and it was possible to start the balancing process. For a balancing process in industry, changes made to the mechanical element are final. For the specimen studied, in the Nylon discs with the slots it was possible to diversify the alterations made, which in this case, screws, nuts and washers were used as balancing masses. This variety of materials ensures that the necessary weight is achieved in the experiment so that balance is achieved. The fig. 3 shows the unbalance.

Balance

Teknikao's software displayed the amount of dough to be added. The program has several functions, and can be adapted in the way that best submits the characteristics of the element being balanced, such as choosing to add or remove mass. It is necessary to point out that for the unbalance level to be measured correctly, the system must be working perfectly without interference from external factors such as vibration of the belt that is in contact with the specimen or failure to read the rotation by the tachometer. These were problems faced during the study to balance the specimen that were solved during the process. Characterizing this unbalanced movement, these forces are generating movements outside the center of inertia and this movement is being received by the accelerometer system in plane 1 and in plane 2 where these arcs of unbalance. It is advisable to repeat this process at different rotations on the balancer until it reaches the working rotation of the element or as close as possible.



a) Right view b) Front view

Figure 2: Balancing rig TEKNIKAO 750 model, 2023

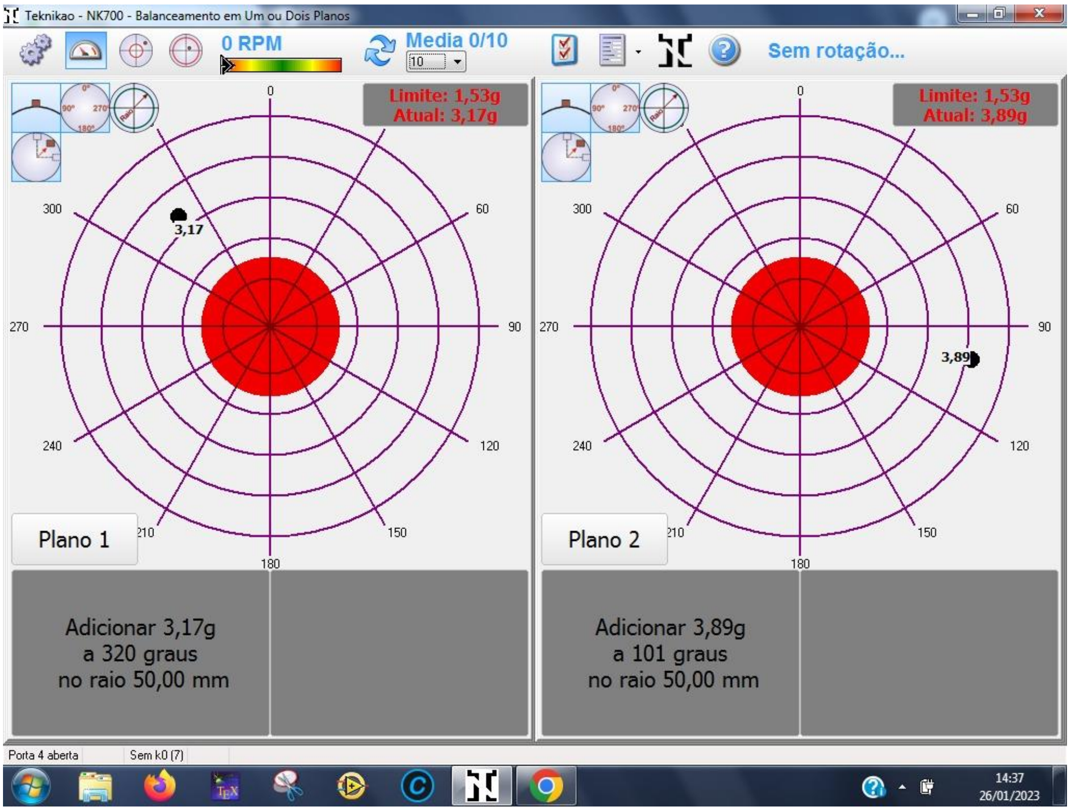
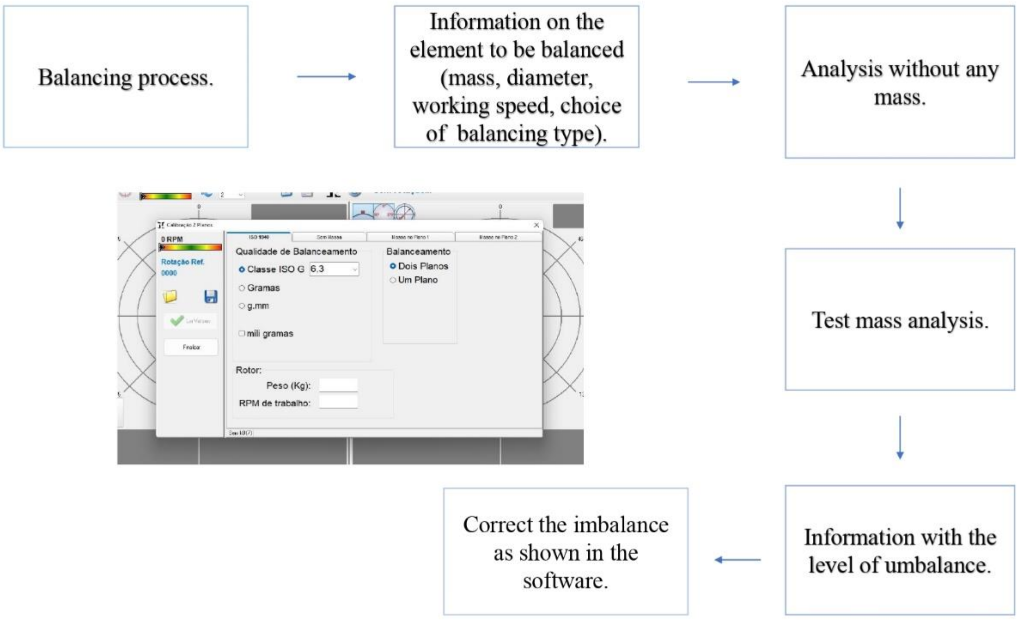


Figure 3: Teknikao software reports alert with the red color to the bad unbalance level. It means that the specimen is unbalanced, according with the grad of quality selected, 2023.

Figure 4: Teknikao software, balance level, 2023.

Balancing process

The image below fig.5 shows a brief outline of the software calibration process for balancing.



Conclusion

It is therefore concluded that problems related to mechanical vibrations in rotating mechanical elements can be solved gradually, ensuring a longer useful life for the mechanical system, in addition to benefiting several other factors, such as economics, quality of work, or good functioning of the machine. At the research level, this experiment sublimely illustrates the process carried out in large industries, whether in balancing an automotive shaft or a crankshaft shaft, making it possible to aim for new ideas so that this process is increasingly optimised.

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