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Balancing and Vibration Control of Rotating Machinery

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Abstract: There are so many devices in today's ever-growing world that have rotating parts, but rotating parts have the primary concern of regulating and managing the vibration. The majority of the machinery includes rotating elements. We had done an in-plant internship project on "Case Study of dynamic balancing of rotating elements". In this paper, a review of the research work performed in real time balancing and vibration control for rotating machinery, as well as the research work on static and dynamic modeling and analysis techniques of rotor systems is presented. We have gained practical knowledge by working on static and dynamic balancing of the impeller in the central machine shop under the engineering shops and foundry department. Vibration suppression of rotating machinery is an important engineering problem. The basic methodology and a brief assessment of major difficulties and future research needs are also provided. The summary of the research work conducted in the actual real-time balance and vibration regulation of rotating machinery in this article. This study paper also addressed the area of research carried out on the rotor system's dynamic and analysis techniques. A short discussion of the approach is also included, as well as a thorough review of the rotating parts technique. In a different application of the technology used in the world, rotating machinery is generally used, i.e. machining machines, automotive turbo machinery, cars and earthmovers. In the small equipment which can be used in the machine, household works, as well as cooking accessories, sometimes rotating parts are used. The consequence of incorrect balance is vibrations. In this review paper, the study has been done for the proper understanding of the Phenomenon and its causes as well as remedies.

Key Words: Balancing, vibration, dynamic analysis, automobile, machine balancing.

1.INTRODUCTION

Balancing is a technique of correcting or eliminating unwanted inertia forces or moments in rotating machinery. During a cycle of operation rotating machinery encounters the shaking forces. Such forces can cause vibrations that at times may reach dangerous amplitudes. Even if they are not dangerous, vibrations increase the component stresses and subject bearings to repeated loads that may cause parts to fail prematurely by fatigue. So we must eliminate, or at least reduce, the dynamic forces that produce these vibrations in the first place. Thus determining the unbalance and the application of corrections is the principal problem in the study of balancing. Any rotor with an uneven distribution of mass about its axis of rotation has an unbalancing. Unbalance always exists when the mass distribution of the rotor with reference to the shaft rotational axis is not symmetrical. The causes of Unbalance can take many forms and can be combined into four groups. Construction and Drawing Errors: e.g. components not symmetric, un-machined surfaces on the rotor, variation in roundness and construction because of coarse tolerances. During a cycle of operation rotating machinery encounters the shaking forces. Such forces can cause vibrations that at times may reach dangerous amplitudes. Even if they are not dangerous, vibrations increase the component stresses and subject bearings to repeated loads that may cause parts to fail prematurely by fatigue. So we must eliminate, or at least reduce, the dynamic forces that produce these vibrations in the first place. Thus determining the unbalance and the application of corrections is the principal problem in the study of balancing. Unbalanced of any rotor with an uneven distribution of mass about its axis of rotation has an unbalancing.

Rotating machinery is commonly used in mechanical systems, including machining tools, industrial turbo-machinery, and aircraft gas turbine engines. Vibration caused by mass imbalance is a common problem in rotating machinery. Imbalance occurs if the principal axis of inertia of the rotor is not coincident with its geometric axis. A great cost savings for high-speed turbines, compressors, and otherturbo-machinery used in petrochemical and power generation industries can be realized using vibration control technology. Although the control system is usually more complicated than a passive vibration control scheme, the vibration control technique has manyadvantages over a passive vibration control technique. First the vibration control is more effective than passive vibration control in general (Fuller et al., 1996). Second,the passive vibration control is of limited use if several vibration modes are excited. Finally, because the actuation device can be adjusted according to the vibration characteristic during the operation, the active vibration technique is much more flexible than passive vibration control. The main purpose of this paper is to review and reevaluate the active vibration control techniques for rotating machinery and shed some light on future research directions.

There are two major categories in vibration control techniques for rotating machinery: direct vibration control techniques directly apply a lateralcontrol force to the rotor, and the balancing techniques adjust the mass distribution of a mass redistribution actuator. The control variable in DVC techniques is a lateral force generated by a force actuator such as the magnetic bearing. The advantage of DVC techniques is that the input control force to the system can be changed quickly.By applying a fast-changing lateral force to the rotating machinery, the total vibration, including the synchronous vibration, the transient-free vibration, and other non- synchronous vibration of the rotating machinery, can be suppressed. The limitation of most force actuators is the maximum force they can provide. In high rotating speed, the imbalance-induced force could reach a very high level. Most force actuators cannot provide sufficient force to compensate for this imbalance-induced force. Under this condition, active balancing methods can be used. In active balancing methods, a mass redistribution actuator (namely, whose mass center can be changed) is mounted on therotor. After the vibration of the rotating system is measured and the imbalance in the rotating machinery is estimated, the mass center of the actuator is changed to offset the system imbalance. The vibration of the rotatingmachinery is suppressed by eliminating the root cause ofthe vibration system imbalance. Contrary to the force actuator, the mass redistribution actuator can provide large compensating force. However, the speed of the mass redistribution actuator is slow. Although active balancing methods can eliminate imbalance induced synchronous vibration, they cannot suppress transient vibration and other non-synchronous vibration.

2.METHODOLOGY

1. Dynamic Unbalance:

The simplest rotor model is the planar rotor model. The plane perpendicular to the rotating shaft is considered. The geometric arrangement of the planar rotor is shown in figure 1.

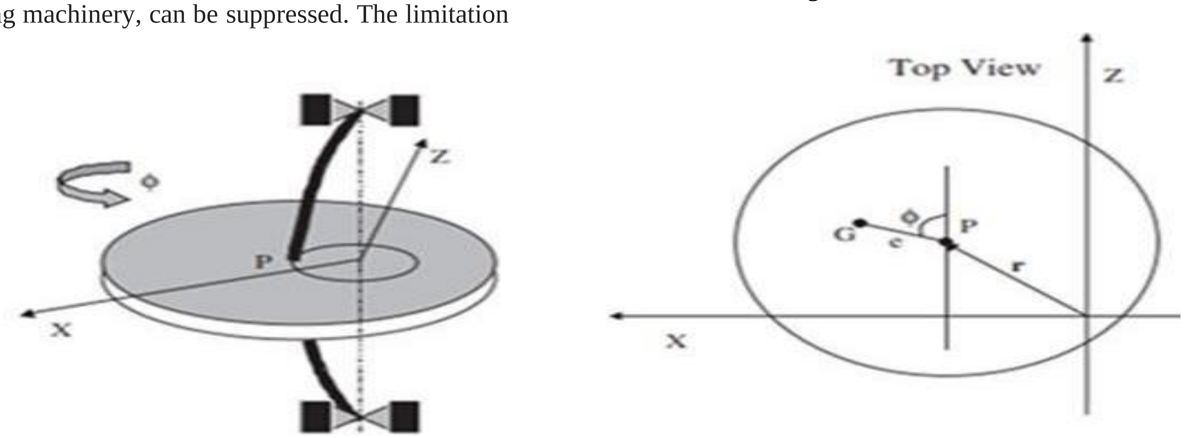

Fig.1 Geometric Arrangement of Planar Rotor

The arrangement described here involves a mass imbalance in a planar rotor. This imbalance causes vibration in the system, with the particle moving around the geometric center of the disc. The disc itself has a mass center represented by G. This arrangement is commonly used to study rotor dynamics, including critical speed, damping, and other fundamental aspects. The rotor is designed to be a rigid disc mounted on fixed rigid bearings, with a shaft that has less elasticity compared to the disc. This setup is similar to a rigid shaft supported by an elastic bearing. The key difference from a simple planar rotor model is that in this arrangement, the motion of the rotor is reflected by rigid body movement rather than particle movement. Although this is a single body model, it can demonstrate various phenomena associated with a rotor in motion, such as forward and backward whirling caused by imbalance forces, critical velocities, gyroscopic effects, and more. Additionally, this model shows that the natural frequency of the system is influenced by the rotating speed. A general depiction of the model's geometric arrangement is shown in figure 2.

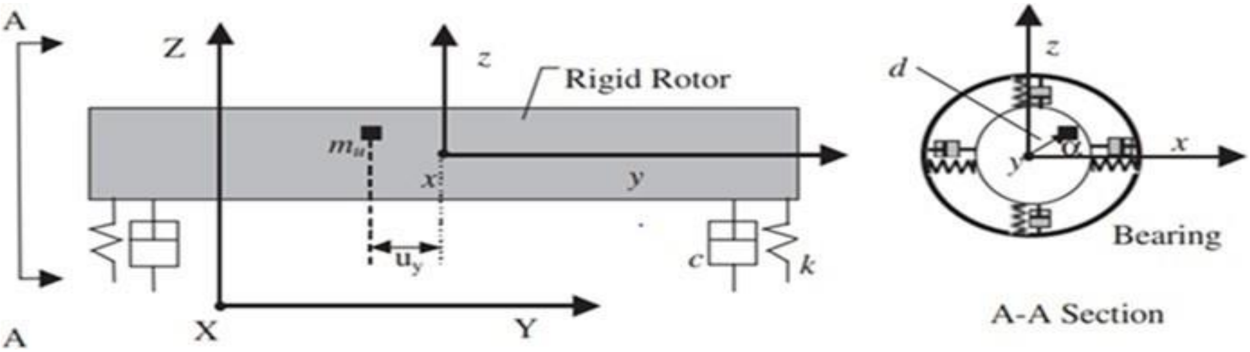

Fig.2 General Geometric of the Model

$$m*a + c*v + k*x = 0,$$

where m is the mass of the rotor, a is the acceleration of the rotor, c is the damping coefficient, v is the velocity of the rotor, k is the stiffness of the bearing, and x is the displacement of the rotor. This equation represents the balance between the inertial forces, damping forces, and spring forces acting on the rotor. The goal is to find the displacement x that satisfies this equation and achieves a balanced state for the rotor.

$$M\ddot{q}+C\dot{q}+Kq = f(\phi)$$

The equation you've mentioned is a representation of a linear system in which the motion of a coordinate q is governed by mass (M), damping coefficient (C), and stiffness (K). This equation is commonly used to study systems with linear ordinary differential equations. However, it is important to note that in real-world scenarios, the assumption of constant rotational speed may not hold true. In transient times, the position of the critical velocity can shift, resulting in a delay in the system's response. This delay is often observed due to the inability to consume energy at the critical speed within the available time.

To address this issue, real-time active balancing methods have been developed. These methods can be classified into passive balancing methods and active balancing methods, depending on the type of balancing device used. Plane rotors, for example, exhibit auto-balancing characteristics due to their dynamic properties. Perturbation theory has also been used to demonstrate that some rotor systems are self-balancing. However, in practical industrial applications, axial movement of particles is often not feasible, making passive balancing less common.

Active vibration control for rotating machinery is a specific application of active vibration control that deals with the control of vibrations in rotating equipment. The dynamics of a rotor system change with the rotation speed, making it necessary to adjust the control gains accordingly for optimal control efficiency. To apply active vibration control to rotating machinery, a non-contact actuator is typically used to apply control power to the rotating shaft. Various types of actuators, such as electromagnetic, hydraulic, and piezoelectric actuators, can be employed for direct active vibration control. One notable technology that has gained popularity in recent years is the active magnetic bearing. Active magnetic bearings use electromagnetic fields to levitate and control the position of the rotor, eliminating the need for conventional mechanical bearings. This technology offers benefits such as improved performance, reduced maintenance, and increased operational flexibility.

When implementing active vibration control for rotating machinery, it is crucial to ensure precise calculations and careful consideration to avoid calculation errors and inaccuracies. This is especially important when the spinning speed of the system is close to the critical speed, as errors in estimating coefficients can lead to significant errors in the correction process of the balancer. Thus, accurate balancing requires meticulous attention to detail.

3.STATIC UNBALANCE

Balancing is an important process in machine design and maintenance to ensure smooth operation and reduce wear and tear on the machinery. Static unbalance occurs when there is a heavy spot on the rotor that causes it to vibrate or oscillate during rotation. This can lead to increased stress on the machine components and decreased efficiency. To correct static unbalance, the rotor can be balanced in a single plane by adding or removing weights at specific locations. This can be done using a balancing machine that measures the imbalance and provides guidance on where the weights should be placed. The goal is to minimize the displacement of the principal axis and achieve a more balanced rotation. Dynamic balancing machines are commonly used for more accurate balancing. These machines rotate the rotor at high speeds and measure the imbalance dynamically. This allows for more precise calculations and adjustments to achieve better balance. Balancing is an iterative process, where the rotor is measured, adjusted, and re-measured until the desired balance is achieved. It is important to note that complete elimination of imbalance is often not possible due to practical limitations, but the goal is to reduce it to an acceptable level. Overall, balancing helps improve the performance and longevity of rotating machinery by minimizing the forces and vibrations caused by imbalance.

4.BALANCING OF SEVERAL MASSES ROTATING IN A SAME PLANE

Let us consider a system which has a several masses (for instance take 4)rotating about the central axis of the shaft which has the masses m_1, m_2, m_3, m_4 and at a distance of r_1, r_2, r_3, r_4 with an angle of θ_1, θ_2, θ_3, θ_4
with respect to the axis OX as shown in figure 3. Let these masses rotate about an axis through O and perpendicular to the plane of paper with a constant angular velocity ω rad/s.

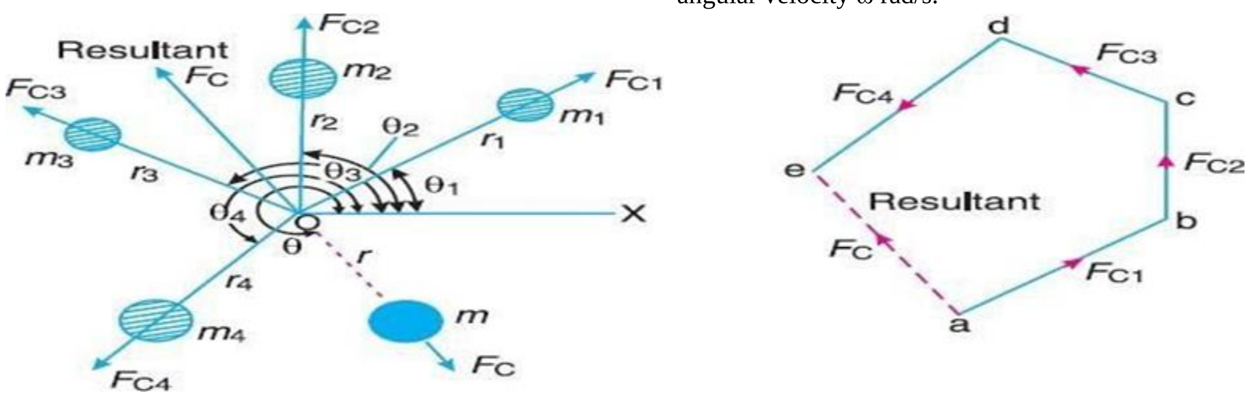

Figure 3

As we know that each mass produces a centrifugal force ($F=mr\omega^2$) radially outwards from the axis of rotation. Let F be the vector sum of the centrifugal forces produced by the masses

$F = m_1 r_1 \omega + m_2 r_2 \omega^2 + m_3 r_3 \omega^2 + m_4 r_4 \omega^2$

The rotor is said to be statically balanced if the above equation is equal to zero and if it is not equals to zero there exists an unbalance so that we need to correct the unbalance by adding the mass or by removing the mass so let's assume there is a correction mass m at a distance r from the origin point O, when the Correction mass is added to the system the above equation becomeszero

$m_1 r_1 \omega^2 + m_2 r_2 \omega^2 + m_3 r_3 \omega^2 + m_4 r_4 \omega^2 + m_c r_c \omega^2 = 0$

$m_1 r_1 + m_2 r_2 + m_3 r_3 + m_4 r_4 + m_c r_c = 0$

One of the parameter m_c or r_c can be fixed and the other can be calculated accordingly. In general, r_c is fixed in the balancing machines known as correction planes so that the distance from the origin Owhere the weight is needed to be added or removed is fixed.

The vector sum of the $m_1 r_1$, $m_2 r_2$, $m_3 r_3$, $m_4 r_4$ can be represented as the

Σmr so that the above equation becomes $\Sigma mr + m_c r_c = 0$

To solve these equations mathematically find the components of forcesin x direction and z direction i.e,

$\Sigma mr\cos\theta + m_c r_c \cos\theta_c = 0$

$\Sigma mr\sin\theta + m_c r_c \sin\theta_c = 0$

$\tan\theta_c = - m_c r_c \cos\theta_c / - m_c r_c \sin\theta_c$

The signs of the numerator and denominator of this function is toidentify the quadrant of the angle.
As we discussed above r_c is fixed and all other masses and their distances can be measured, we get the mass thatneed to be added to clear the unbalance produced and from the equation and we get the angle at where the correction mass is added on thecorrection plane.

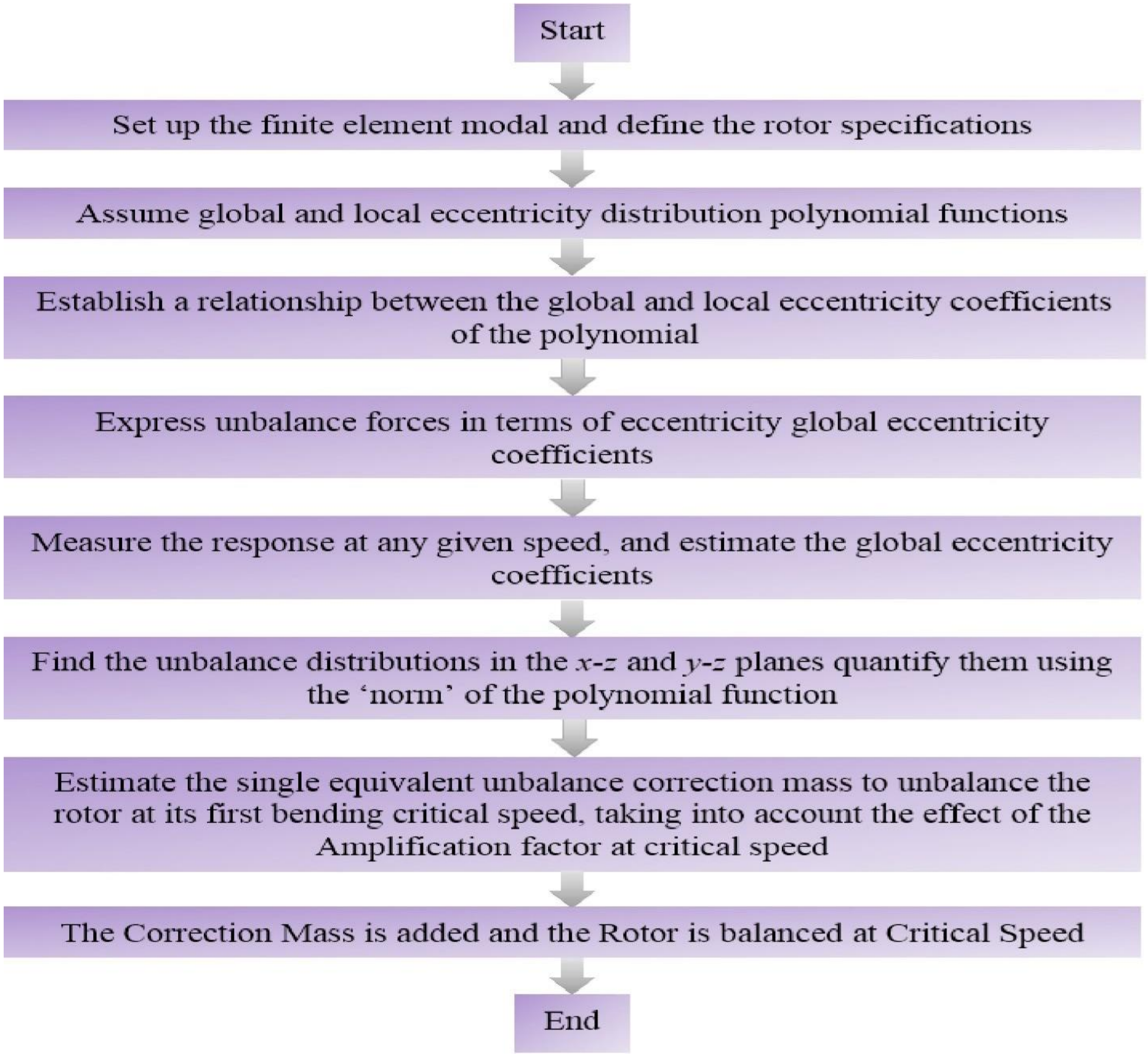

Figure 4. Flow chart of the balancing methodology

4.BENEFITS OF DYNAMIC BALANCING

Having a machine operating in balance can have numerous positive consequences. Some of these outcomes include:

1. Low vibration: When a machine is in balance, it experiences minimal vibrations, which is crucial for its smooth operation and longevity. Excessive vibrations can lead to wear and tear on the machine components, reducing its lifespan.
2. Low noise: A balanced machine operates quietly, reducing noise pollution in the working environment. This can improve the overall comfort and productivity of the operators.
3. Operator fatigue: A balanced machine puts less strain on the operator, reducing fatigue and improving their efficiency and productivity.
4. Operator safety: Balanced machines are less prone to unexpected breakdowns or malfunctions, enhancing

operator safety. It reduces the risk of accidents caused by mechanical failures.
5. Increased bearing life: Balanced machines experience reduced stress on their bearings, leading to increased bearing life. This decreases the frequency of maintenance and replacement, saving time and cost.
6. Reduced structural stress: Imbalanced machines can put excessive stress on their structures, leading to premature wear and potential structural failures. Operating in balance reduces such stress, extending the machine's lifespan.
7. Low operating cost: By reducing vibrations, structural stress, and the risk of breakdowns, balanced machines require less maintenance and repairs, ultimately leading to lower operating costs.
8. Increased productivity: A balanced machine operates at optimal efficiency, resulting in increased productivity and output. It reduces downtime and allows for smoother production processes.
9. Safe working environment: Balanced machines contribute to a safer working environment by minimizing risks associated with mechanical failures, vibrations, and excessive noise.

The study of dynamics and vibration control in rotating machinery is essential for both industry and academia. By understanding and implementing active balance and direct vibration control techniques, engineers can minimize vibrations induced by imbalance while accurately estimating and controlling the imbalance itself. This research can serve as a scientific foundation for developing efficient and reliable adaptive control systems for balancing and vibration control in various types of machinery.

5.CONCLUSION

Balancing rotating machinery is indeed essential to prevent vibrations, which can cause stress and damage to the bearings. It's great that you had the opportunity to learn about different types of unbalance and the importance of balancing in heavy machinery. It's also fascinating to hear that you were given the chance to balance the ID fan impeller with the guidance of an operator. Hands-on experience can greatly enhance understanding in engineering fields. In order to achieve effective balancing and vibration control, it's crucial to develop reliable and efficient techniques. This involves investigating the coupling effect between the estimation algorithm, system dynamics, and control performance. By understanding these factors, it becomes possible to design a generic adaptive control system that can effectively correct or eliminate imbalances. Your research in this area has the potential to make a significant contribution to the field, providing a scientific basis for designing advanced control systems that can improve the balance and vibration control of rotating machinery.

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