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Dynamic Analysis of Support Frame Structures of Rotating Machinery

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Abstract- Adequate dynamic analysis of support frame structures of mechanical equipment is necessary to ensure not only the comfort of the users, but ensure good conditions for the operation of equipment supported. Studies of dynamics structural and equipment see the difficulty performing real models. This paper conducts a performance check of the support frame structures, according to changes in their connections, considering the loads caused by rotating machinery and compared with the limits of displacements of the structures established by standards of equipment and structures. The use of a computational numerical model that represents the most real way possible system to be analyzed is required. This article is to conduct a study establishing a practical application of dynamic loads caused by rotating equipment on supports with different connections structures using computational models with STRAP software. Models of structures with connections rigid, pinned and semi-rigid, will be made, applying loads of rotating machines and viewing which support base has the best performance in relation structure versus dynamic loading in accordance with connections.

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DYNAMICANALYSISOFSUPPORTFRAMESTRUCTURESOFROTATINGMACHINERY

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Dynamic Analysis of Support Frame Structures of Rotating Machinery

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Abstract- Adequate dynamic analysis of support frame structures of mechanical equipment is necessary to ensure not only the comfort of the users, but ensure good conditions for the operation of equipment supported. Studies of dynamics structural and equipment see the difficulty performing real models. This paper conducts a performance check of the support frame structures, according to changes in their connections, considering the loads caused by rotating machinery and compared with the limits of displacements of the structures established by standards of equipment and structures. The use of a computational numerical model that represents the most real way possible system to be analyzed is required. This article is to conduct a study establishing a practical application of dynamic loads caused by rotating equipment on supports with different connections structures using computational models with STRAP software. Models of structures with connections rigid, pinned and semi-rigid, will be made, applying loads of rotating machines and viewing which support base has the best performance in relation structure versus dynamic loading in accordance with connections.

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I. Introduction

Dynamics of structures studies movements of bodies caused by forces applied to them and also the forces that cause movements in structures. Steel and concrete structures are elements subjected to forces, and these structures must resist in order to maintain the shape similar to the desired settings during the operation. According to Brasil and Silva (2013), the movements of a structure must be sufficiently minor around a projected initial configuration. The adequate dynamic analysis of structures implies the creation of models that allow converting a pre-established entity, in a complex way, into something that the current resources can understand and model. Thus, according to Brasil and Silva (2013), at the beginning the real structure is transformed into a physical (or conceptual) model, by simplifications such as bars, plates, idealized supports, materials of simplified behavior, punctual masses, etc. From then, a mathematical model is constructed, a system of equations relating the characteristics of the structure, and introducing the laws of mechanics. In the final stage, we try to solve these equations by analytical or numerical means. Currently, the processes of mathematical modeling and of numerical solution were transformed by the advent of computing through modeling software.

It is noteworthy that Ferreira (2002) in his elaborated studies indicated that to find the answer in the field of structure's dynamic analysis, analyses can be performed either in the time domain or in the frequency domain, where each analysis must be performed according to the predominance. For instance, in the situation soil-structure the frequency domain analysis prevails.

Vibrations of mechanical equipment such as rotating machinery, should be strictly controlled according to the application and the criteria of existing technical standards and of those that are still being studied, and should be used as basis of the operating conditions of mechanical equipment, especially for predictive maintenance. In his studies, Soeiro (2008) shows that predictive maintenance is a format in which it is considered that equipment or machinery, usually in operation, should have continuous and scheduled monitoring with the objective of detecting flaws such as unbalance, misalignment, widespread clearance, bad fixing, unbalanced electric field, etc.

Premature wear of machine components, unexpected breakage of parts, structural fatigue of the equipment and of its support base, disconnection of parts, and even a possible unplanned stop of the equipment are flaws in machinery that cause excessive vibrations of parts of the equipment and can cause damage to the industrial processes.

Among the above-mentioned essentials of maintenance, in order to control the phenomena of vibration, three different procedures must be followed, considering the latter as the focus of this study: Attenuation of the response: alteration in the structure (reinforcements, auxiliary masses, changing of natural frequency, etc).

II. Considerations for the Design of Steel Frame Support Structures

According to previous researches, it was considered that the effect of dynamic loads on civil structures could be related to the increase of static load. However, in recent researches, it was observed that these studies did not represent correctly the effect of

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dynamic loads on structures, since the analysis of the effects caused by a dynamic load is very different from the analysis of the effects caused by a static load. Thus, characteristics inherent to each type of activity that generates a dynamic excitation should be considered as loads that have frequency, amplitude, and shape, which lead structural systems to different types of disarrangements. Thus, in the REFERENCES we present the main standards used in the research that refer to the analysis of structures subjected to dynamic actions and criteria related to the analysis of human comfort and good performance of mechanical equipment.

III. Considerations on Dynamics of the Rotors of Rotating Machinery

In the numerical simulation of rotor dynamics, the formulation of a mathematical model that represents a rotating system requires prior knowledge of the project parameters such as dimensions and material data. The success of a rotating machine project consists mainly of:

- Avoiding critical velocities, if possible;
- Minimizing the dynamic response in resonance peaks, if necessary;
- Passing through a critical speed;
- Avoiding instability;
- Minimizing vibrations and loads transmitted to machine structure throughout the period of operation.

The critical speeds by which a machine can pass until reaching its operating speed become one of the major inconvenient in rotor dynamics. At these speeds, the machine shaft can reach higher amplitudes of vibration that can cause irreversible damage to the bearings and to other components of the rotor.

In the case of a rotor shaft with conventional materials, the possible ways to reduce the amplitude of critical speeds is to balance the rotor, which means go to the source of the problem – however, it is very difficult to balance a rotor with perfection.

We can also change machine speed rotation to avoid critical speeds, or change the speed by varying the rigidity of the bearings. If the machine has to operate at a critical speed, the solution is to add external damping to the rotor. This property can be used in rotor dynamics, when it is necessary to reduce the amplitudes of vibration if the machine is at a critical speed. It is also necessary to have simplifying hypotheses that make the numerical model practical, without mischaracterizing its behavior.

a) *Handbook of Machine Foundations (1976)*

Another reference found in the technical literature on the theme available – Srinivasulu and Vaidyanathan (1976) – provides a simpler table of limit values of vibration amplitudes for different types of machine that will be used for the validation of the proposed models.

b) *Unbalanced Forces In Rotating Machinery*

According to Brasil and Silva (2013), for an unbalanced force rotating around an axis, the procedure to have this force acting in the vertical plane, pointing to "all" directions, is to apply this force in two orthogonal directions, one in the horizontal with phase t_0 equals zero, and one in the vertical direction with phase t_0 equals ¼ of the period of vibration of this unbalanced force. Thus, as time progresses, there is a variation of two forces so that the composition of them will be the unbalanced force, for one will be multiplied by $sin\ (\omega t)$ and the other by $sin\ (\omega t + \pi/2)$, and while one is maximum, the other is null, and vice versa.

IV. Modelling of the Dynamic Load

The model consists of 2 motor-pump sets (electric motor and hydraulic pump) on a platform (steel frame), Figures 1 and 2, one with its axis oriented transversely to the frame and the second with its axis oriented longitudinally. According to the STRAP program, we are considering the transverse displacements as X3, longitudinal displacements as X1 and vertical displacements as X2.

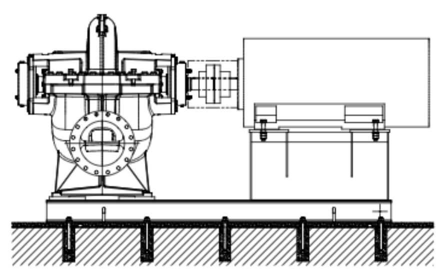


Fig. 1 : Motor-Pump set. Source: KSB Pumps

- Information about the Electrical Motor:

Total Mass: M_{Tm} = 9,448 kg

Quality of the unbalancing: Q = 2.5 mm/s

Operation frequency: f = 60 Hz

Information about the Pump KSB RDLO 350 575:

Total Mass: M_{Tb}= 2,600 kg

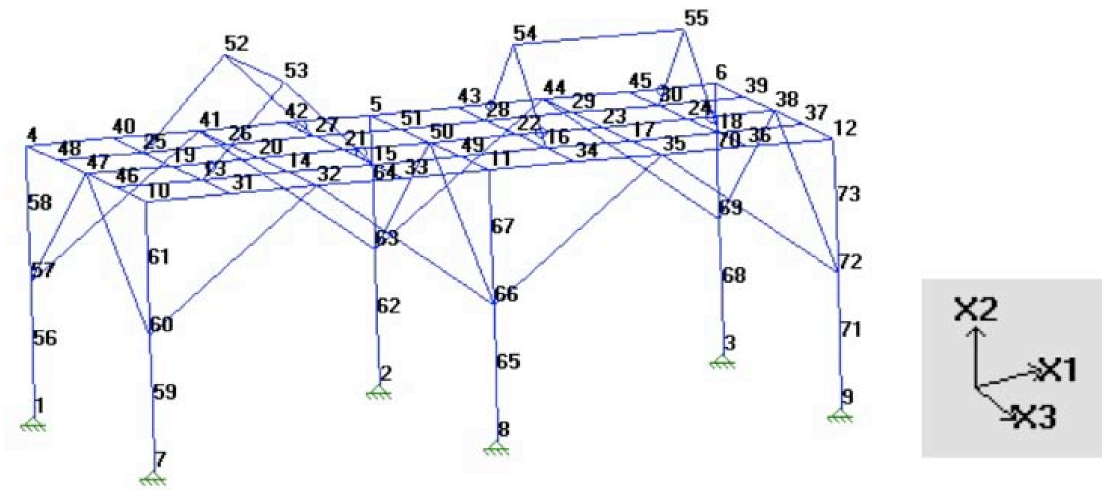
Information about the Structure:

Columns and Principal Beams: Section W410x38.8

Secondary Beams and Braced Frames: Section W380x44.5

Equipment: Rectangular geometric section with steel properties with the total weight of the set

Damping coefficient: 0,8%



Source: Author

Fig. 2 : Indication of the structure nodes

a) Initial Considerations – Application of Nodal Weights And Computational Models

The distribution of the masses of the pieces of equipment depends on the position of the gravity centers of the pieces of equipment, of the rotors, and on how these devices are laid on the structure. In the model, the total mass of each Motor-Pump Set is considered to be of 12,200 kg, whit the application showed in Table 1, and was fully applied on the supporting points of its axis. The mass of the structure was applied on its Nodes as Nodal Weights (the weight of the Sections is considered; however, it is not presented).

Table 1 : Application of Mass on the Nodes of the Motor-Pump Sets

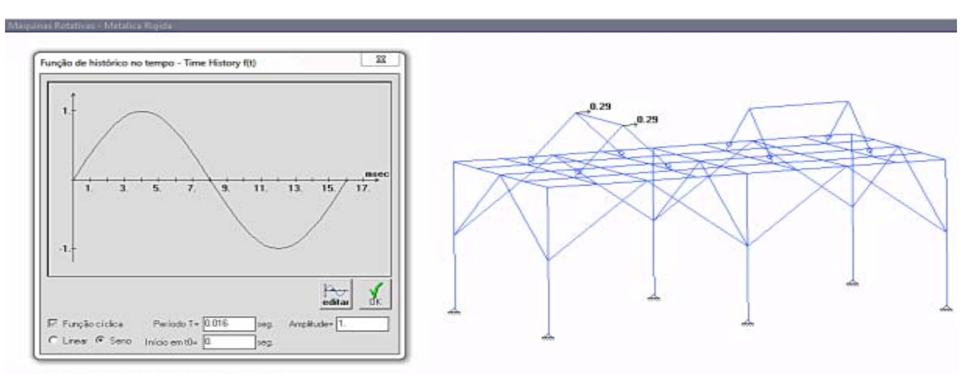
Set	Application point	Mass
CMB1	Node 52 e 53	12,200 kg
CMB2	Node 54 e 55	12,200 kg

Source: Author

b) Description of Dynamic Load – Calculation of the Equipment's Dynamic Forces

The unbalance of the motor-pump set generates a centrifugal force, which depends on the total mass of the set distributed in the two points of the axis, on the eccentricity between the center of gravity of the rotor and the geometric axis of rotation, and on the angular velocity of the set. In this studied was considered the dynamic loads applied to the nodes like the table 2 and showed at Figure 3.

$$F_T = M_{\frac{Cmb}{2}} . Q . \Omega = 6100 . (0.0025) . (60.2\pi) =$$
$$= 5749.11N \cong 0.58t$$



Source: Author

Fig. 3 : Dynamic Force 1 applied to the model

Table 2 : Dynamic Loads applied to the Nodes

Loads	Force - Nodes	Direction
CMB1-X1 - f=60Hz - T=0.016s - t0=0.00s	0,29 tf - 52/53	X1
CMB1-X2 - f=60Hz - T=0.016s - t0=0.004s	0,29 tf - 52/53	X2
CMB2-X3 - f=60Hz - T=0.016s - t0=0.00s	0,29 tf - 54/55	X3
CMB2-X2 - f=60Hz - T=0.016s - t0=0.004s	0,29 tf - 54/55	X2

Source: Author

V. Results and Discussion

a) Dynamic Analysis of the Structure

Having defined the two orthogonal loads (forces) for each piece of equipment, we combine them in the dynamic analysis module, so that the results are added instant by instant of time of each dynamic load, and never the maximum of them are added as separate loads. After the dynamic load applied into STRAP software, in the Module "Time History", we can view the maximum nodal amplitudes in continuous operation, with answers in the period from 10.0 to 10.1 seconds at nodes 52, 53, 54, and 55, thus verifying which structure has the best performance in the relation load/nodal displacement. It is noteworthy that the machine manufacturers have their limits of displacements, in general, based on the Handbook of Machine Foundations, by Srinivasulu and Vaidyanathan (1976). All amplitude values presented by STRAP software are showed in Table 3.

b) Analysis of the Amplitudes

According to the amplitudes, or displacements, showed in table 3, we observed that the displacement generated in the three models have a small variation between the structures and all within the permitted standards according to Handbook of Machine Foundations de SRINIVASULU e VAIDYANATHAN (1976).

Table 3 : Displacements in Strap Models

Displacements in Strap Models:	Displacements in X1 of combination 1 on Node 52 (mm)	Displacements in X2 of combination 1 on Node 52 (mm)	Displacements in X3 of combination 2 on Node 54 (mm)	Displacements in X2 of combination 2 on Node 54. (mm)
Dynamic analysis of model I – rigid connections:	0,0480	0,0031	0,0238	0,0029
Dynamic analysis of model II – semi-rigid connections:	0,0483	0,0031	0,0244	0,0029
Dynamic analysis of model III –pinned connections:	0,0507	0,0031	0,0253	0,0029

Source: Author.

In the displacement in X1 of combination 1 on node 52, the rigid structure had the best performance, semi-rigid structure second best performance and pinned structure had the worst performance.

In displacements in X2 of combination 1 on node 52, the rigid, pinned and semi-rigid structures had the best performance, equal in this case.

In displacements in X3 of combination 2 on node 54, the rigid structure had the best performance, semi-rigid structure second best performance and pinned structure had the worst performance.

In displacement in X2 of combination 2 on node 54, the rigid, pinned and semi-rigid structures had the best performance, equal in this case.

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VI. Conclusion

The structural model studied has a well-sized rigidity. What was observed is that intuitively the use of fully rigid structures may be the best solution from the dynamic structural point of view. However, it was verified that in the three models all the amplitudes are in accordance with Handbook of Machine Foundations, by Srinivasulu and Vaidyanathan (1976), and according to other analysis conducted with STRAP, the results related to velocities – which are not presented in this work – are also in accordance standard Deutsche Norm – Vibrations in Buildings – Part 3: Effects on Structures: DIN 4150-3 (1999).

This article demonstrates that when there are well-founded theoretical basis and adequate computational tools the making of an effective and dynamic calculation of the equipment and structure can be simple and with more capacity of the structural engineer to recommend the best structure considering its connections. Then, considering the software STRAP, which is practical for use in research, the calculations of structural dynamics may be more reliable. Finally, the article is suggested as a reference for future calculations of supporting structures of rotating machinery, and as a suggestion we recommend the actual construction of the models.

VII. Acknowledgments

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