Extended abstract

Model for quality control and engineering risk assessment of industrial machine foundations

Rafael Godinho Pires

Instituto Superior Técnico, Portugal

Abstract

Our modern life and its level of technologic development is supported by industrial machinery which allows for the commodity we experience nowadays. Industrial machine foundations are a common engineering challenge and have been neglected by the main manufacturing companies in Portugal, with high costs that are not desirable in competitive industries in case risks are not well address.

The different specialties of construction and mechanics allows the achievement of the actual state of development, but the market competitiveness and scale economies drive to the continuous search for improved productivity and pay back. Regarding these two last aspects, it is therefore critical to develop and implement management systems and technical control tools to verify and certify the quality of the construction.

This research attempts to improve machine foundation systems performance and a model was developed to assess and verify technical control measures for the construction of industrial machines foundations. It aims to promote performance and its longevity as well as the quality of the built systems. Moreover it prevents associated technical risks.

The aim of this research is to evaluate and improve performance of construction of foundations for heavy industrial machinery in what concerns its durability and robustness. Additionally, it includes the development of a model and an application for technical control, during the conception and construction of industrial machines foundations.

Keywords:

Industrial Machines, Industry, Technical control, Quality control, Technical risk, Foundations for industrial machinery

1. Introduction

The present dissertation is “Model for quality control and engineering risk assessment of industrial machine foundations ” and regards construction management, industrial and factories management, risk management and quality control in the area of civil engineering.

The present model was developed in order to analyze measures of technical control for quality improvement of machine foundations. This proposal applies exclusively to the construction of machinery foundations in block, or sets of blocks, for industrial machines, enclosing the following lifecycle phases of these constructive systems: Diagnosis, Conception, Execution and Reception of machine foundations.

The research attempted to track the basic aspects of this thematic and aims to offer a contribution to the technician who applies the resulting model. It provides a more comprehensive understanding of the challenge that such enterprise involves as well as guidance for model application.

The use of industrial machines demands high maintenance and their inactivity has elevated costs. Therefore it is necessary to achieve a better return by objectively improving the machines´ potential. In this context, concepts for machines management and maintenance were developed, as well as guidelines for organization, planning and technical control aspects, related with foundations systems. These guarantee the fulfillment of their original requirements and functions, still in conformity with their technical attributes.

In the industrial machines sub-sector, there is a series of specific techniques, of high complexity, that are neglected by the great majority of stakeholders, especially in the heavy and metalworking industries. As consequence, economical and technical problems may arise from the lack of dialogue between technicians and managers, the majority of which have no clear culprits. These problems can be minimized and prevented with the implementation of the proposed model during different steps of the lifecycle foundation. That is, since its conception until the end of the exploration time.

It is necessary to guarantee that the entire foundation project and execution are strictly controlled, since foundations are the main structure that support load transference and leads to waste of energy. Its adequate conception and execution promotes a better functioning and equipment stability.

With this dissertation it is intended to provide a model in order to identify fragilities, to define strategies that guarantee the stakeholders interests, by managing, supporting decisions, preventing and sharing risks, as well, machines performance.

2. Machine foundations

The machine foundations systems are a dynamic problem, where dynamic forces are generated by the different types of functioning machines. The challenge lies essentially in the way systems respond to them according to the different types of machines functioning. The foundation system response depends on the geometric features of the foundation, the surrounding soil, the features and peculiarities of the machine functioning and the materials used in the engineering solution. The critical challenge regarding foundations consists in determining the response to impulses, that is, the foundation block supports the machine and transmits accelerations to the support structure; then, the latter reacts to the impulses according to its rigidity characteristics.

Determining the system natural frequency is the main aspect to consider when sizing the foundation. It depends on the mass, the rigidity and the damping, being the latter proportional to the machine functioning speed. The challenge here is to guarantee the permissible shifts and accelerations of the machine foundation systems and the stability throughout its lifecycle.

To solve the problem, there are different structural possibilities with the following major aims: to transmit all forces to the ground; to isolate from interferences coming from the exterior; and to guarantee the ideal stability conditions, operation and occupational safety. On the other hand, it is necessary to assume the foundation as an integrant part of the all structure, where machine functioning, environment, bracket systems, environment actions and interactions, participate and determine the block size that constitutes the foundation system.

The dynamic forces produced by the machine functioning have a relatively low absolute value, comparatively with the static ones, but its repetitive character and the generated frequencies can amplify these forces and shifts which consist in the resonance phenomena. If not verified, in *situ*, the ideal ground features, an increase in the deformation of the foundation may take place in function of the load-dump cycles thus affecting machine stability. As consequence, the lack of permanence in a known balance state reduces the occupational safety and negatively affects other attributes such as, equilibrium and durability.

2.1 – Machine types

The industrial machines can be classified according to their main movement and operation speed, as described in Tables 1 and 2, respectively.

Table 1 - Types of industrial machines

Main movement	Example
Rotative	Turbines, compressors, fans, centrifugal machines
Alternative	Compressors, combustion engines
Impulsive	Presses, hammer units, guillotines, pistons
Other	Crushers

Table 2 – Machines classification according to their operation speed

Operation speed	< 100 rpm	**Very low**
	≥100 e ≤ 1500 rpm	**Low**
	> 1500 e ≤ 3000 rpm	**Medium**
	> 3000 rpm	**High**

Industrial machines can also be classified according to its output power, as stipulated by the ISO 10816 and as detailed in Table 3.

Table 3 - Machine classification according to their power output (ISO 10816)

Class	Elements	Example	Output power
I	Individual parts of engines and machines, hardwired with the full machine in conditions of normal functioning	Electric motors	< 15 kW
II	Machines of medium size, engines or machines rigidly assembled	Electric engines, without special foundations	> 15 e ≤75 kW
		Engines or machines with special foundations	< 300 kW
III	Heavy motor machines and other machines with assembled rotating masses on rigid and heavy foundations	Generators, fans	n.d.
IV	Great motor machines with assembled rotating masses on flexible foundations	Turbo-generators	n.d.

The machines main movement is known through the characteristic impulses that is introduced in the structures. As a consequence of the different main movements, forces are produced that differ in amplitude, leading to specific needs to balance and isolate the system. The type of movement evaluation, indicates if the foundation system (geometry, mass and form) is adjusted to transmit the forces that are generated to the ground.

2.2 Foundation types

The engineering foundation solution depends on some factors, which include the machine type, static and dynamic forces generated by the machine, project conditions, physical limitations, shifts, accelerations, safety requirements and limits.

Depending on the described factors, different foundation types can be applied/are available as shown in Figure 1.

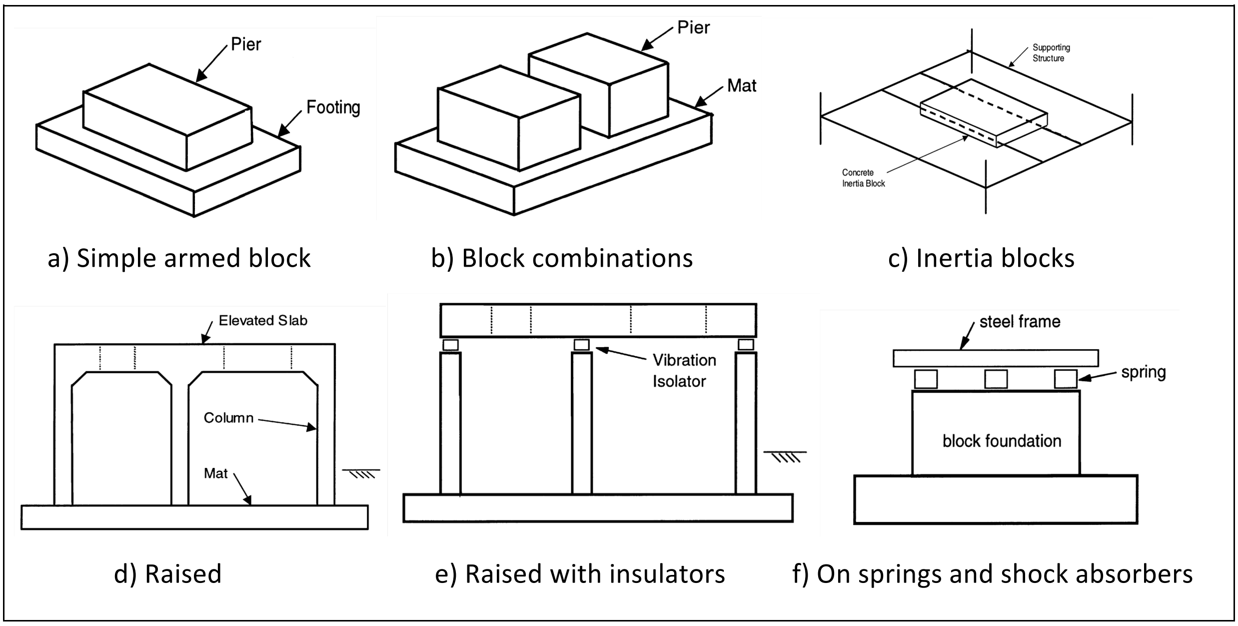

Figure 1 – Foundation systems

Table 4 presents the relationship between the machine movements types and the adequate foundation solutions.

Table 4 – Movement type and adequate machine foundation system

Movement type	Main movement	Machine type	Operating speed	Adequate Foundation system
Periodic	Uniform rotation	Rotative machines: Generators, electric motors, turbines,	>1000 rpm	Frames Simple armed block + bracket base Inertia blocks + Insulators
	Uniform rotation + Straight movement	Alternative machines: Internal combustion engines Piston compressors	0 – 500 rpm	Inertia blocks + bracket base
			300 – 1000 rpm	Insulated blocks
Non-periodic	Impulsive + shock Impacts	Impulsive machines: Hammers Forge hammers	n.d.	Mass or leaked blocks + shock absorbers

3. Model

The proposed model for technical control includes the following procedures: accompaniment; fiscalization; planning verification; auditorships; quality control; and evaluation of risks operations related with the machine foundations.

This model schedules the procedures regarding the implementation of the foundation with the aim of achieving a reduction of the operation and maintenance costs during the machine lifetime. Expectantly, it provides a simple and yet thorough tool for information acquisition, it guides and advises which are the best practices and corrective measures to ensure the main objectives of the foundation system.

The model was developed and based on three major principles: quality improvement; performance improvement and technical risk management.

Quality improvement

To reach the quality improvement, the different areas of construction, mechanics and management are synergistic to optimize production processes thus making them more cost effective while, in the same process, meeting quality standards, the stakeholder's interests and client satisfaction.

To achieve quality improvement, strategic procedures are developed in function of the continuous quality improvement concept and aim to improve the management quality through monitoring processes to sustain and assist decision making.

Performance improvement

The desirable high efficiency of production centers not only depends of good equipment functioning, but particularly of the perfect toggle between systems. Machines can be both receiver and source of vibrations and interference situations have negative consequences for systems performance. It is the civil and mechanic engineers´ responsibility to build structures and bracket systems to prevent vibrations and its propagation.

The present model offers verification techniques and tools to control the aspects that negatively affect the performance, safety, durability and efficiency of machine-foundations systems.

Engineering risk management

In the present model proposal, the risk management activities lie on the identification, analysis and mitigation of the risks associated to the system conceptions and execution. It is carried out by comparing the best practices applied to the construction of machine foundations, by evaluation of the exposition to the defined risks and by the technician experience.

These criteria for risk assessment intend to verify, evaluate the techniques and elements that affect the system attributes.

The aggravation factors help to evaluate the exacerbation of risk, but there are no definitive references to define it.

3.1 Stakeholders

Expectantly, this model enhances the successful construction, use maintenance and safety of heavy machines, it is especially useful to official authorities and regulators, owners, contractors, financial entities, fiscal entities, technical control organisms and insurers.

With the application of this model, it is intended to diminish the stakeholders concerns, to construct with controlled risks and to contribute for the resolution of inherent conception and execution problems and challenges, with clear definition of the specific responsibilities of all the different intervening parties.

We are in the presence of systems composed of different mechanical and construction products that interact and work together, establishing valuable equipment, to fulfill the demanding functional requirements. Therefore, strict control measures must be applied to get the maximum return from the system, which should ideally be limited only by the machine itself and not by the foundation system. This is a very important aspect for all the intervening third-parties, especially for insurance companies, therefore the “macro definition of the responsibilities is clearly defined by the identification of system limitations” (Almeida, 2011).

3.2 Model structure

The technical control model for foundations of industrial machines lies in a set of reports that give guidance for risk assessment and definition, having into account the presented aspects for the the diagnosis, conception and execution phases. See Table 5.

Table 5 – Structure of the model

Structure of the model of control of the quality and the risk of engineering of foundations for industrial machines				
Boarded aspects	**Phases**			
	Diagnostic Chapter 4 Annex I	**Conception** Chapter 5 Annex II	**Execution** Chapter 6 Annex III	**Reception** Chapter 7 Annex IV
Project revision	✓	✓	✓	
General aspects	✓	✓	✓	
Inspections	✓			✓
Loads and requests		✓		
Limit states		✓		
Soil improvement		✓	✓	
Constructive details		✓	✓	
Materials	✓	✓	✓	
Measurements	✓		✓	
Previous jobs			✓	
Assays	✓		✓	✓
Job delivery				✓

The diagnosis phase report, presents and compels a series of verifications and activities for technical control, analysis and evaluation of the existing systems. This phase report, identifies the system actual state of condition and allows to determine a general risk degree for the inherent engineering activities.

The conception phase assists in the understanding, the identification and risk analysis of the project data base, calculus models and the chosen engineering solutions.

In the report, Annex II - Report of Conception, some procedures and verifications that are suggested allow to guarantee that the solution is well adjusted to the problem; that it includes practical rules that are tuned according to the type of project; and that it allows to inquire/identify not-conformities and risks.

In the execution phase, the activities of technical control focus on the physical execution and have the objective to assure the requirements specified in the previous phases of project, in the fulfillment of regulations, laws, as well as good practices and recommendations for any given type of machine foundations construction.

The engineering risks contemplated in the developed activities tries to ensure accidental losses, resulting on the following:

- Accidents resulting from project errors, man work and materials faults;
- Failures and detailing errors;
- Damages and anomalies consequence of structural insufficiency;
- Material damages in the installations, machines and handling equipment;
- Occurrence of resonance;
- Extreme vibrations;
- Inadequate layout and patterns to the work conditions, operations of installation, functioning and maintenance;
- Resultant accidents of the movement of machines, loads and people;
- Extraordinary works;

The developed evaluation criteria have been defined according to following guidelines:

- Errors and defaults: errors of calculation and contradictions between different project documents;
- Environment conditions: proximity of dangerous zones, chemically aggressive environments and contaminated lands/grounds;
- Foundation ground: low resistant capacity, existence of water, structural characteristics;
- Contiguous or nearby structures: proximity of machines and underground installations;
- Pre-existences: areas where interventions are forbidden , ancient structures with heritage value;
- Non conventional/standard techniques or materials;

4. Diagnosis of machine foundations

The present evaluation of existing systems is the first procedure to be applied in the rebuild process of industrial machines foundations. This chapter recommends a set of procedures to evaluate the structure and its components.

At the beginning of the diagnosis phase, the data and information are collected and recorded on the report that consists of the Annex I - Report of Diagnosis. These data are the basis for the conception phase.

The diagnosis phase comprises the procedures regarding the project revision and inspections to evaluate the state and the performance of the constructed system.

5. Conception of machine foundations

The conception phase is subdivided into three groups as can be consulted in the report in Annex II - Report of Conception. It contains a set of questions and verifications related with the following subjects:

General information on the machine and system

- Loads
  - Service Limit State
  - Last Limit State
- Constructive details on:
  - Grout
  - Bed and bracket system

The model provides specific information, good practices and recommendations for the conception and sizing of the machine-foundation systems

The report intends to be a working document which contains verifications and operations for a better engineering conception applied to machine foundations.

6. Execution of machine foundations

The execution phase consists in the ultimate phase of the physical system construction.

The referred procedures must continuously be carried out during the execution process. Assays must be performed though, whenever necessary, to certify and assure that the elements are well executed.

Whenever some not-conformity regarding to the foundation? execution is verified, , such as materials and/or used techniques, a report must be emitted and the process interrupted. The problems that led to the suspension must be immediately analyzed and solved to mitigate possible associated risks.

The constructive details have a direct relation with the quality and the maintenance of the quality of the constructed systems. The system resists and respond to dynamic and static loads and it is necessary to guarantee the good execution of all elements to assure that anomalies do not occur during the operation lifetime.

7. Reception of machine foundation

The job site delivery estimates leaving the site ready for machine installation and alignment by the team responsible for these activities.

This is a milestone of the activities planning. In the act of reception, all the related reports should be delivered, which must be totally filled and must contain all the proof documents of the assays.

In the reception act, all the pre-operational verifications must be carried out. it includes the verification of the drawn parts and, if necessary, execution of proof tests for the programmed performance that should be mentioned in the final report, Annex IV, and only then, should the guarantee be activated.

8. Conclusions

The present dissertation aims to provide the best engineering solutions for the construction of foundations for industrial machines and to support the engineering risk evaluation.

This research hopes to promote and to guarantee the safety, use and durability of the system foundations. It ensures the maintenance of valuable equipment and the safety, health and environment standards reflecting owners and users needs.

This model can be applied to high standards markets, the aeronautical, electronics and automobile industries are examples of markets of enormous potential where precision is the key-element to guarantee the desired final high quality standards.

The present recommendations facilitate problem resolution. From the financial point of view, it has been noticed that the application of this model has a vestigial cost *versus* the overall value of the entire construction . The benefits of its application are therefore extremely positive and valuable regarding waste reduction and it also includes orientations to evaluate risk. However, its application also implies high experience and knowledge from from the user.

This model proposal must be customized and completed according to specific management needs and plans and having into account the requirements of the diverse types of industrial machines. It is also important to develop a quantitative scale for risk, calibrated and customized according to the problematic of the foundations of industrial machines. It allows to positively extend the field of application of the model, contributing for the evaluation of diverse systems to be constructed and/or to be controlled.