Atena
Editora
Ano 2021

Ernane Rosa Martins
(ORGANIZADOR)

Ciência, tecnologia e inovação:

2

Fatores de progresso e de desenvolvimento

Atena
Editora
Ano 2021

Ernane Rosa Martins
(ORGANIZADOR)

Ciência, tecnologia e inovação:

2

Fatores de progresso e de desenvolvimento

Editora chefe
Profª Drª Antonella Carvalho de Oliveira
Editora executiva
Natalia Oliveira
Assistente editorial
Flávia Roberta Barão
Bibliotecária
Janaina Ramos
Projeto gráfico
Natália Sandrini de Azevedo
Daphynny Pamplona
Camila Alves de Cremo
Luiza Alves Batista
Maria Alice Pinheiro
Imagens da capa
iStock
Edição de arte
Luiza Alves Batista

O conteúdo dos artigos e seus dados em sua forma, correção e confiabilidade são de responsabilidade exclusiva dos autores, inclusive não representam necessariamente a posição oficial da Atena Editora. Permitido o *download* da obra e o compartilhamento desde que sejam atribuídos créditos aos autores, mas sem a possibilidade de alterá-la de nenhuma forma ou utilizá-la para fins comerciais.

Todos os manuscritos foram previamente submetidos à avaliação cega pelos pares, membros do Conselho Editorial desta Editora, tendo sido aprovados para a publicação com base em critérios de neutralidade e imparcialidade acadêmica.

A Atena Editora é comprometida em garantir a integridade editorial em todas as etapas do processo de publicação, evitando plágio, dados ou resultados fraudulentos e impedindo que interesses financeiros comprometam os padrões éticos da publicação. Situações suspeitas de má conduta científica serão investigadas sob o mais alto padrão de rigor acadêmico e ético.

Atena
Editora
Ano 2021

Prof. Dr. Arnaldo Oliveira Souza Júnior – Universidade Federal do Piauí
Prof. Dr. Carlos Antonio de Souza Moraes – Universidade Federal Fluminense
Prof. Dr. Crisóstomo Lima do Nascimento – Universidade Federal Fluminense
Profª Drª Cristina Gaio – Universidade de Lisboa
Prof. Dr. Daniel Richard Sant'Ana – Universidade de Brasília
Prof. Dr. Deyvison de Lima Oliveira – Universidade Federal de Rondônia
Profª Drª Dilma Antunes Silva – Universidade Federal de São Paulo
Prof. Dr. Edvaldo Antunes de Farias – Universidade Estácio de Sá
Prof. Dr. Elson Ferreira Costa – Universidade do Estado do Pará
Prof. Dr. Eloi Martins Senhora – Universidade Federal de Roraima
Prof. Dr. Gustavo Henrique Cepolini Ferreira – Universidade Estadual de Montes Claros
Prof. Dr. Humberto Costa – Universidade Federal do Paraná
Profª Drª Ivone Goulart Lopes – Istituto Internazionele delle Figlie de Maria Ausiliatrice
Prof. Dr. Jadson Correia de Oliveira – Universidade Católica do Salvador
Prof. Dr. José Luis Montesillo-Cedillo – Universidad Autónoma del Estado de México
Prof. Dr. Julio Candido de Meirelles Junior – Universidade Federal Fluminense
Profª Drª Lina Maria Gonçalves – Universidade Federal do Tocantins
Prof. Dr. Luis Ricardo Fernandes da Costa – Universidade Estadual de Montes Claros
Profª Drª Natiéli Piovesan – Instituto Federal do Rio Grande do Norte
Prof. Dr. Marcelo Pereira da Silva – Pontifícia Universidade Católica de Campinas
Profª Drª Maria Luzia da Silva Santana – Universidade Federal de Mato Grosso do Sul
Prof. Dr. Miguel Rodrigues Netto – Universidade do Estado de Mato Grosso
Prof. Dr.Pablo Ricardo de Lima Falcão – Universidade de Pernambuco
Profª Drª Paola Andressa Scortegagna – Universidade Estadual de Ponta Grossa
Profª Drª Rita de Cássia da Silva Oliveira – Universidade Estadual de Ponta Grossa
Prof. Dr. Rui Maia Diamantino – Universidade Salvador
Prof. Dr. Saulo Cerqueira de Aguiar Soares – Universidade Federal do Piauí
Prof. Dr. Urandi João Rodrigues Junior – Universidade Federal do Oeste do Pará
Profª Drª Vanessa Bordin Viera – Universidade Federal de Campina Grande
Profª Drª Vanessa Ribeiro Simon Cavalcanti – Universidade Católica do Salvador
Prof. Dr. William Cleber Domingues Silva – Universidade Federal Rural do Rio de Janeiro
Prof. Dr. Willian Douglas Guilherme – Universidade Federal do Tocantins

Atena
Editora
Ano 2021

Ciência, tecnologia e inovação: fatores de progresso e de desenvolvimento 2

Diagramação: Maria Alice Pinheiro
Correção: Amanda Costa da Kelly Veiga
Indexação: Gabriel Motomu Teshima
Revisão: Os autores
Organizador: Ernane Rosa Martins

Dados Internacionais de Catalogação na Publicação (CIP)

C569 Ciência, tecnologia e inovação: fatores de progresso e de desenvolvimento 2 / Organizador Ernane Rosa Martins. – Ponta Grossa - PR: Atena, 2021.

Formato: PDF
Requisitos de sistema: Adobe Acrobat Reader
Modo de acesso: World Wide Web
Inclui bibliografia
ISBN 978-65-5983-600-0
DOI: https://doi.org/10.22533/at.ed.000212010

1. Ciência. 2. Tecnologia. 3. Inovação. I. Martins, Ernane Rosa (Organizador). II. Título.
CDD 601

Elaborado por Bibliotecária Janaina Ramos – CRB-8/9166

Atena Editora
Ponta Grossa – Paraná – Brasil
Telefone: +55 (42) 3323-5493
www.atenaeditora.com.br
contato@atenaeditora.com.br

Atena
Editora
Ano 2021

DECLARAÇÃO DOS AUTORES

Os autores desta obra: 1. Atestam não possuir qualquer interesse comercial que constitua um conflito de interesses em relação ao artigo científico publicado; 2. Declaram que participaram ativamente da construção dos respectivos manuscritos, preferencialmente na: a) Concepção do estudo, e/ou aquisição de dados, e/ou análise e interpretação de dados; b) Elaboração do artigo ou revisão com vistas a tornar o material intelectualmente relevante; c) Aprovação final do manuscrito para submissão.; 3. Certificam que os artigos científicos publicados estão completamente isentos de dados e/ou resultados fraudulentos; 4. Confirmam a citação e a referência correta de todos os dados e de interpretações de dados de outras pesquisas; 5. Reconhecem terem informado todas as fontes de financiamento recebidas para a consecução da pesquisa; 6. Autorizam a edição da obra, que incluem os registros de ficha catalográfica, ISBN, DOI e demais indexadores, projeto visual e criação de capa, diagramação de miolo, assim como lançamento e divulgação da mesma conforme critérios da Atena Editora.

Atena
Editora
Ano 2021

DECLARAÇÃO DA EDITORA

A Atena Editora declara, para os devidos fins de direito, que: 1. A presente publicação constitui apenas transferência temporária dos direitos autorais, direito sobre a publicação, inclusive não constitui responsabilidade solidária na criação dos manuscritos publicados, nos termos previstos na Lei sobre direitos autorais (Lei 9610/98), no art. 184 do Código penal e no art. 927 do Código Civil; 2. Autoriza e incentiva os autores a assinarem contratos com repositórios institucionais, com fins exclusivos de divulgação da obra, desde que com o devido reconhecimento de autoria e edição e sem qualquer finalidade comercial; 3. Todos os e-book são *open access, desta forma* não os comercializa em seu site, sites parceiros, plataformas de *e-commerce,* ou qualquer outro meio virtual ou físico, portanto, está isenta de repasses de direitos autorais aos autores; 4. Todos os membros do conselho editorial são doutores e vinculados a instituições de ensino superior públicas, conforme recomendação da CAPES para obtenção do Qualis livro; 5. Não cede, comercializa ou autoriza a utilização dos nomes e e-mails dos autores, bem como nenhum outro dado dos mesmos, para qualquer finalidade que não o escopo da divulgação desta obra.

Atena
Editora
Ano 2021

APRESENTAÇÃO

A presente obra tem como proposito ser um guia aos estudantes e profissionais de diversas áreas, auxiliando-os em diversos assuntos relevantes, fornecendo a estes novos conhecimentos para poderem atender as necessidades das organizações.

Deste modo, esta obra reúne debates e análises acerca de questões relevantes, tais como: indicadores de desempenho para monitoramento e medição do planejamento e desenvolvimento de produtos de vestuário; metodologia para a execução de testes em um ambiente de integração contínua (IC); forma eficiente e inteligente entre a comunicação do usuário do aplicativo de saúde com vítima e unidades de pronto atendimento de saúde e hospitais; roadmap do mercado cervejeiro, com foco na etapa de mosturação da fabricação de cerveja, de modo a diagnosticar a situação atual e apresentar tendências, por meio da construção de cenários futuros; discussão a respeito da relação das mulheres com a Ciência, em particular Marie Curie e Chien-Shiung Wu; uso da Inteligência Competitiva (IC) para o desenvolvimento de um modelo de negócios por meio de um tripé formado pela criação, configuração e apropriação de valor no segmento de Baby Shops; modelo de fundação para máquinas rotativas sob cargas dinâmicas e vibrações em arranque transitório e funcionamento contínuo, restringindo o seu modo de vibração usando três heurísticas diferentes; projeto “Pneumática Interativa” que tem como objetivo facilitar o aprendizado da pneumática básica para alunos da área de eletrotécnica, através de material interativo; Revisão Sistemática da Literatura (RSL), que pretende apresentar os estudos existentes sobre Geometria Espacial entre os anos 2015 e 2020; a influência do jogo de xadrez ao longo da história de vida da famosa Phiona Mutesi;

Nesse sentido, esta obra apresenta enorme potencial para contribuir com análises e discussões aprofundadas sobre assuntos relevantes, podendo servir de referência para novas pesquisas e estudos. Agradecemos em especial aos autores dos capítulos, e desejamos aos leitores, inúmeras e relevantes reflexões sobre as temáticas abordadas.

Ernane Rosa Martins

SUMÁRIO

CAPÍTULO 8

OPTIMIZAÇÃO HEURÍSTICA DA FUNDAÇÃO DE UMA MÁQUINA ROTATIVA QUE LIMITA AS SUAS VIBRAÇÕES EM MODO DE ARRANQUE E DE FUNCIONAMENTO PERMANENTE

Data de aceite: 01/10/2021
Data de submissao: 06/07/2021

Juan Luis Terrádez Marco
Universitat Politécnica de Valencia, Camino de Vera s/n 46.022 Valencia, Spain. Departamento de Ingeniería de la Construcción y Proyectos de Ingeniería Civil.
Orcid: 0000-0002-2671-7849

Antonio Hospitaler Perez
Universitat Politécnica de Valencia, Camino de Vera s/n 46.022 Valencia, Spain Departamento de Ingeniería de la Construcción y Proyectos de Ingeniería Civil.
Orcid: 0000-0001-7108-3104

Vicente Albero Gavarda
Universitat Jaume I, Avenida de Vicente Sos Baynat s/n 12071 Castellón de la Plana, Spain. Departamento de Ingeniería Mecánica y Construcción.
Orcid: 0000-0001-7193-9232

RESUMO: Este documento propõe a optimização de um modelo de fundação para máquinas rotativas sob cargas dinâmicas e vibrações em arranque transitório e funcionamento contínuo, restringindo o seu modo de vibração usando três heurísticas diferentes. É proposto um modelo de fundação com parâmetros fixos e 37 variáveis. As restrições funcionais são definidas para a fundação. As restrições de vibração são aplicadas de acordo com as normas ISO 10816 e VDI 2056 NORM em modo transiente e funcionamento. É calculada uma função de custo em função das variáveis. De todas as soluções possíveis são seleccionadas apenas as que validam as restrições e minimizam a função de custo. Para pesquisar estas soluções são utilizadas três heurísticas de pesquisa aleatória por vizinho de um ponto chamado Pesquisa Local Descendente (DLS), Recozimento Simulado (SA) e Escalada de Última Aceitação (LAHC). O DLS não aceita soluções piores para obter a optimização, o SA aceita soluções piores seguindo um horário de arrefecimento e o LAHC é um algoritmo do tipo "Adaptative Memory Programming" (AMP) que aceita soluções piores para obter o mínimo local e conhecer os resultados. Foi desenvolvido um programa MATLAB para obter os resultados. O conjunto de resultados de cada pesquisa é ajustado a uma distribuição de 3 parâmetros Weibull para calcular o parâmetro de localização que é considerado como o óptimo teórico global. Finalmente, é analisado o vizinho ao parâmetro de localização de cada conjunto de resultados e o tempo de execução de cada heurístico. O DLS obteve o melhor óptimo da base. Todo o conjunto de variáveis óptimas atinge os constrangimentos propostos. As três heurísticas conseguiram o óptimo das fundações com soluções próximas do óptimo local com a conformidade dos constrangimentos de vibração propostos. O DLS é o algoritmo mais rápido para obter o óptimo. SA é o mais lento. A fundação concebida e o cálculo da aceleração do arranque reduz consideravelmente os deslocamentos horizontais e verticais que não são críticos durante o modo transitório e o modo de funcionamento permanente.

PALAVRAS - CHAVE: Fundação, vibrações, optimização, heurística, pesquisa local de descida, recozimento simulado.

HEURISTIC OPTIMIZATION OF THE FOUNDATION OF A ROTATIVE MACHINE CONSTRAINING ITS VIBRATIONS IN STARTING AND PERMANENT OPERATION MODE

ABSTRACT: This paper proposes the optimization of a model of foundation for rotative machines under dynamic loads and vibrations in transient starting and continuous operation restricting its vibrations mode using three different heuristics. A model of the foundation is proposed with fix parameters and 37 variables. Functional constraints are defined for the foundation. Vibration constrains are applied according to ISO 10816 and VDI 2056 NORM in transient and operation. A cost function depending on the variables is calculated. From all the possible solutions only are selected the ones that validate the constrains and minimize the cost function. To search these solutions three heuristics of random search by neighbouring of one point called Descent Local Search (DLS), Simulated Annealing (SA) and Last Acceptance Hill Climbing (LAHC) are used. DLS does not accept worse solutions to get optimal, SA accepts worse solutions following a cooling schedule and LAHC is an algorithm of the "Adaptative Memory Programming" (AMP) type that accepts worse solutions to get the local minimum and learn of the results. A MATLAB program was developed to get the results. The set of results of each search is fitted to a distribution of 3 parameters Weibull to calculate the location parameter that is considered as the theoretical global optimal. Finally, it is analysed the neighbouring to the location parameter of each set of results and the runtime of each heuristic. DLS got the best optimum of the foundation. All the set of variables optimal achieve the constrains proposed. The three heuristics got the optimum of the foundations with solutions nearby to the local optimum with the compliance of the vibration constrains proposed. DLS is the faster algorithm to get the optimum. SA is the slowest. The foundation designed and the rump-up of the starting calculated reduces considerably the horizontal and vertical displacements not being critical during the transient and the permanent operation mode.

KEYWORDS: Foundation, vibrations, optimization, heuristics, Descent Local Search, Simulated Annealing.

1 | INTRODUCTION

Calculation of the foundations of industrial machines under dynamics loads is based in "rules of thumb method" focused in increasing the weight and volume of the foundation to reduce the vibrations that the machine transmits in continuous operation mode.

Displacement, speed, and acceleration of the machine are calculated with complex mathematical formulas based on the operating parameters of the machine and soil.

These results would show make big foundations it is due to the increase of the mass that reduces considerably the vibrations. To achieve the equilibrium between the size of the foundations and the vibrations is only possible calculating in the time domain. And this calculate permits to analyze what happens with the vibrations during the transient operation mode, since 0 speed to nominal speed.

D'Alambert differential equations based in the Lysmer and Richart (1996) analogy, combined with the integration step by step with the β Newmark (1959) method permits to analyze displacement, speed and acceleration during the transient and continuous operation mode (Chowdury et alter.,2009).

During the operation of a machine, in the starting, the machine can cross the resonant frequency, where the amplitude of the displacement is increased out of reasonable limits and damage the machine. To resolve this difficulty a foundation model is proposed. Limit of the displacement according to, ISO 10816-1995, speed according to Norm VDI 2056 Norm and acceleration according to Blake Chart of 1964 (ACI 351.3R-04, 2004)(Terrádez and Hospitaler, 2020).

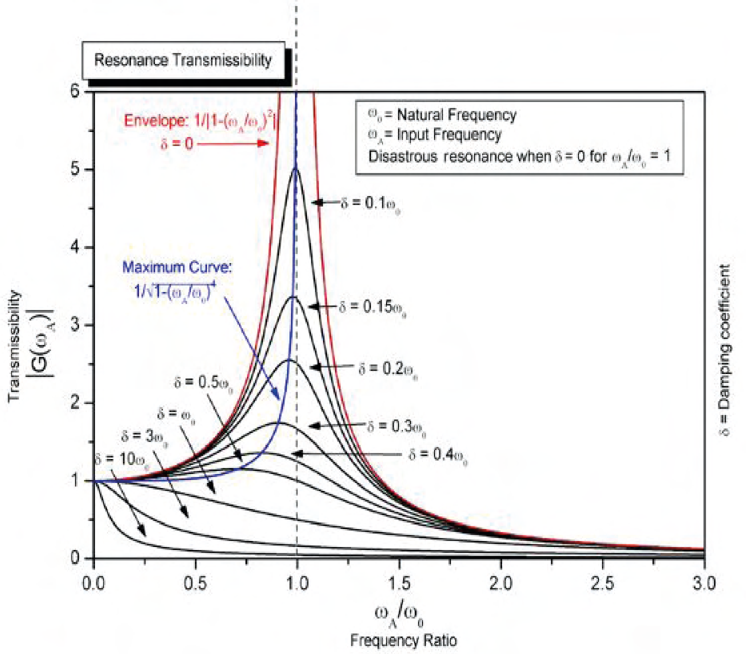


Figure 1. Resonance Transmissibility.Source: ACI Norm 351.3R-04, 2004

Authors proposed different methodologies to optimize the foundations of industrial machines.

Sienkiewicz, Z. and Wilczynski, B. (1993) proposed the optimization of a single degree of freedom system (S.D.O.F. in advanced) based in the weight of the block foundation. Impedances of the soil were calculated using the Novak model.

When calculating the displacement, the Richart-Whitman's model of lumped parameters is used. And for the Poisson soil parameter will be considered using the values of Richart (1970).

Besides, the cost function depended on the three parameters of the block foundations, length, wide and height. Restrictions considered were the resonance frequency, vertical displacement, value limits of length and wide of the block and stresses in the soil.

For solving, authors considered the problem as a “sequence linear programming” (SLP). An initial solution was calculated, and small changes were made by Taylor approximation using the Gauss simplex algorithm around the solution. The convergence of the algorithm was not guaranteed if the variables are not limited. Two examples were calculated.

Moreover, Sienkiewicz, Z. and Wilczynski, B. (1996), proposed the optimization now based on the volume of the block foundation.

The machine was under vertical loads and mounted on the block. Soil parameters were calculated under the half-space theory. Vertical, sliding and rocking displacement were considered, in fact, three degrees of freedom. Authors solved the problem in the frequency domain using the complex variable.

The function to optimize was the volume of the foundation with two variables, length and wide. Height was considered fixed.

Restrictions considered were the vertical displacement, horizontal displacement, value limits of length and wide of the block and stresses in the soil.

For solving, authors considered the problem as a “sequence linear programming” (SLP) using Taylor’s series around the solution. To guarantee stability and convergence of the algorithm the limits of the variables were fixed. An example of a reciprocating machine was calculated.

Silva, Marcelo et alter (2002) proposed a concrete elevated structured used for steam turbines for its optimization. The dimensions of the structure and the reinforcement steel were the design variables to be optimized. A cost function was defined depending on concrete, reinforcement steel and the shape of the structure.

Restrictions considered were the limits of the material and the stresses on the soil. To calculate the structure a finite elements analysis was employed. Movement equations were developed with a lumped parameters method.

Limits of displacement, speed and acceleration were considered from the graphics in Arya et alter (1979).

Optimization of the cost function was solved by five numerical methods in the time domain. A numerical example was included. Conclusions were that computation time is too long, about forty days and could be reduced to four days using approximations.

Anyagebunam, A.J. (2011) optimised the foundation on an elastic half-space using lumped parameters designing a minimum weight foundation.

With the Richart’s (1966) parameters and the Lysmer’s (1970) analogy equations and operating the equations in function of a parameter “D” of damping, they obtained a function to get a minimum. Mass of the foundations was a function of the parameter D and was derivate to get the minimum mass.

Anyagebunam considered that the minimum got were too small for the size of the machine. Size of the foundations is not compatible with the size of the machine. An example was included.

Authors considered only the continuous mode of working of the machine, but, what happens during the transient starting from 0 to the operation speed? Introduction of the variable time in the calculation of the foundation of a machine means analyse transient starting too.

2 I OBJECTIVES

The foregoing review of the literature reveals that research in optimization methodologies of the foundations has been based in classical methodologies. Heuristics have been applied in the optimization of structures but not employed in the optimization of the foundations.

A previous study of the natural resonance frequency of the set foundation-machine it is necessary to guarantee the cross during the transient operation mode or the neighbouring during the permanent operation mode.

The study of the performance during the transient and the permanent operation mode could be made integrating the D'Alambert differential equations of the set foundation -machine in the time domain. Vibrations can be analysed, and foundation can be fitting to constrain them using an iterative process.

As a result, the objective of this work is to apply three different heuristics to optimize the foundation constraining its vibrations and compare the results obtained and the resources employed.

Heuristics are the methodology proposed to get the optimal solution. Now, there are to look for the possible solutions, the ones that satisfy the constrains, and after, look for the optimal of them.

Three heuristics are proposed that look for the optimum using the methodology of Variable Neighbourhood Search (VNS). It would all depend on a simple concept: the systematic change of the structure of the neighbouring used for the searching.

Methodologies of one-point iterative search start with a random solution call "actual solution". Stochastics searching produces the best solutions with an iterative process. In each iteration (movement) actual solution is modified to get a candidate solution to be the actual solution. A candidate solution is checked and could be accepted or rejected depending on the acceptance criteria selected. If the candidate solution is accepted, then becomes the actual solution and a new "movement" starts. If the candidate solution is rejected a new random search starts with actual solution for the next iteration. An "converging condition" is established to consider that a new movement will not get a better solution and stop the search.

The minimum of a function "cost" implemented for the foundation of a rotative machine under dynamics loads is calculated with the heuristics DLS, SA and LAHC.

Objective is to get the optimal foundation that will be the cheapest of all the foundations calculated for each set of variables in the transient and continuous operation mode.

As the cost function is a non-continuous function of many variables there are infinite set of values of the variables for the minimum but not all achieve with the constrains. Only a searching process done with a heuristic could calculate the optimal solution. Three questions are considered in this paper to analyse the solution got it:

1.- Can the heuristics methodologies be applied to get optimal of the cost function of the foundation model proposed for the machine under dynamics loads in transient starting and continuous operation mode?

2.- Which of the three heuristics expends less runtime to get a reliable solution?

3.- How reliable is the solution get it taking in to account and how far is from the global optimum?

The first heuristic that is performed is called Descent Local Search (DLS). The simplest heuristic to get the best possible solution. It is a methodology of searching by variable neighbouring where the difficulty is delimiting the limits of each variable and select in each movement the number of variables to move to get the optimum in the way which would be more efficient. Only better candidate solutions are accepted.

To improve the searching worse candidates are accepted than the actual solution. If all the candidates are accepted, the search degenerate into the introduction of a series of "random perturbations" (DLS).

The second heuristic is proposed by Kirpatrick, Gellat and Vecci (1983) called Simulated Annealing (SA). Traditionally cooling schedules have been introduced that permit accept worse solutions regulated by an arbitrary system control defined by one parameter. This parameter must get a final value where candidate solutions are not accepted that produces worst movements and the search converges.

Furthermore, the third heuristic, Last Acceptance Hill Climbing (LAHC), is an iterative algorithm of one point searching that accepts worst movements when the candidate is equal or better than a solution accepted a number of iterations before. Algorithm LAHC is simple, easy to be implemented and an effective methodology to search better solutions.

The one point searching algorithm with "Hill Climbing" methodology was mainly developed by Appleby et alter (1961). It is a quick methodology but sometimes not enough powerful because is blocked in local optimum.

This algorithm differs from the SA in:

1.- It does not employ a cooling schedule

2.- The using of the fitting array employing the information collected during the searching follows the idea of “intelligent” use of information

This idea call “Adaptative Memory Programming” (AMP) was developed by Taillard et alter (2001).

Do the set of variables selected by the algorithm achieve the vibration constrains applied? Which is the main constrain of the 3 applied? The vibration produced by the operation of the machine is analysed in the transient mode and continuous operation mode for each one of the set of variables solution.

Not only the variables of construction of the foundation are selected to get the optimal, the best operation variables in the starting up of the machine are searched by the heuristic.

3 I METHODOLOGY

It is especially important to establish the levels of vibration, alert, and alarm level, to optimize the vibration analysis and guarantee the correct operation of the machine. In that way, it is necessary a good design of the foundation and the anchors that guarantee a tolerable vibration since the beginning of the operation.

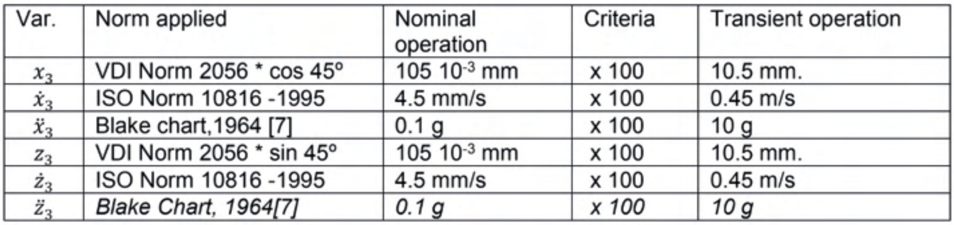
Wear of the machine will necessarily increase that vibrations until intolerable levels. Different criteria were established to classify the severity of the vibration of the machines to consider shutting down when machine could be damaged.

For the transitory operation mode, there was not any norm or reference that propose any limit to the displacement, speed, or acceleration. Only Rodriguez et alter (2010) in their paper, commented that sensors of the amplitude of movement of the turbine were disconnected in the transitory operation mode. The constrains for the transitory operation mode were proposed by the author of this paper to limit the possible cross of the resonance frequency during the period since starting to the permanent operation.

For the machine, acceleration, speed, and displacements were defined applying the VDE and ISO Norm and the Blake Chart.

For the transient mode there are not any criteria defined. According to manufacturer, 100 times the permanent operation mode is right. Less than 10 mm. of displacement is safe for the machine.

Rodriguez et alter (2010) explained that during the starting of the 330 MW turbogenerator, sensors must be disconnected because the displacements in the transient operation mode that they measure were not permitted in normal operation mode. There are not criteria in those cases.



Var.	Norm applied	Nominal operation	Criteria	Transient operation
x_3	VDI Norm 2056 * cos 45°	105 10^{-3} mm	x 100	10.5 mm.
$\dot{x}_3$	ISO Norm 10816 -1995	4.5 mm/s	x 100	0.45 m/s
$\ddot{x}_3$	Blake chart,1964 [7]	0.1 g	x 100	10 g
z_3	VDI Norm 2056 * sin 45°	105 10^{-3} mm	x 100	10.5 mm.
$\dot{z}_3$	ISO Norm 10816 -1995	4.5 mm/s	x 100	0.45 m/s
$\ddot{z}_3$	*Blake Chart, 1964[7]*	*0.1 g*	*x 100*	*10 g*

Table 1 constraints of operating the machine. Limits of displacement, speed and acceleration in -X and -Z axis of the machine at nominal operation and transient operation. Source: authors

The optimization problem lies in founding, inside a set “X” of feasible solutions, the solution x that optimizes the function f(x). Problem of minimization is established as follows:

$$min[f(x)\ I\ x \epsilon X]$$

Whereas:

- x is an alternative solution.
- f is the objective function.
- X is the space of feasible solutions for the problem.

An optimal solution x* (or global minimum) of the problem is a feasible solution where the minimum of the function is got it.

If X is the set of solutions finites and discrete, but of big size, we are in front of a problem of optimization combinatorial.

A structure or neighbouring of the set of solutions is an application.

N: X--------- 2x

That combine each solution x € X to a set of solutions N(x) included in X, in the vicinity of x. The methodologies of local search applied to a transformation or movement towards the solution, and they use, implicitly or explicitly, a surrounding structure. The surrounding of a solution x € X will be all the solutions that you can get since x with a movement or transformation of the solution.

A feasible solution x* € X is a global minimum of the problem if not exists a solution x € X such as the objective function f(x) < f(x*).

The solution x’ € X is a local minimum respecting to N if not exist a solution x € N(x’) included in X such f(x) < f(x’).

3.1 Descent Local Search

A descent local search consists basically of finding iteratively a better solution from the actual solution by means of introducing a disturbance o movement. The classic greedy descendent searching consists in always replacing the actual solution by the best of all the solutions that you can get from the actual doing a movement. The search will be stopped when is not possible to find the best solution in the vicinity of this.

Choosing the correct movement is decisive for the success of the local search and difficultly can be determined “a priori” as to which of the possibilities will be the more effective.

1	Starting: select a random solution S1
2	Check the constrains
3	If it’s feasible a random movement produces a solution S2
4	The cost of S2 is calculated and if Cost(S2) < Cost (S1)
5	Check the constrains for S2
6	If S2 meets with the constrains, S2 converts in S1 and the process starts again
6	If Cost(S2) > Cost (S1) or S2 doesn’t meet with the constrains, a new movement is done from S1 and the process starts again

Table 2 Process DLS. Source: authors.

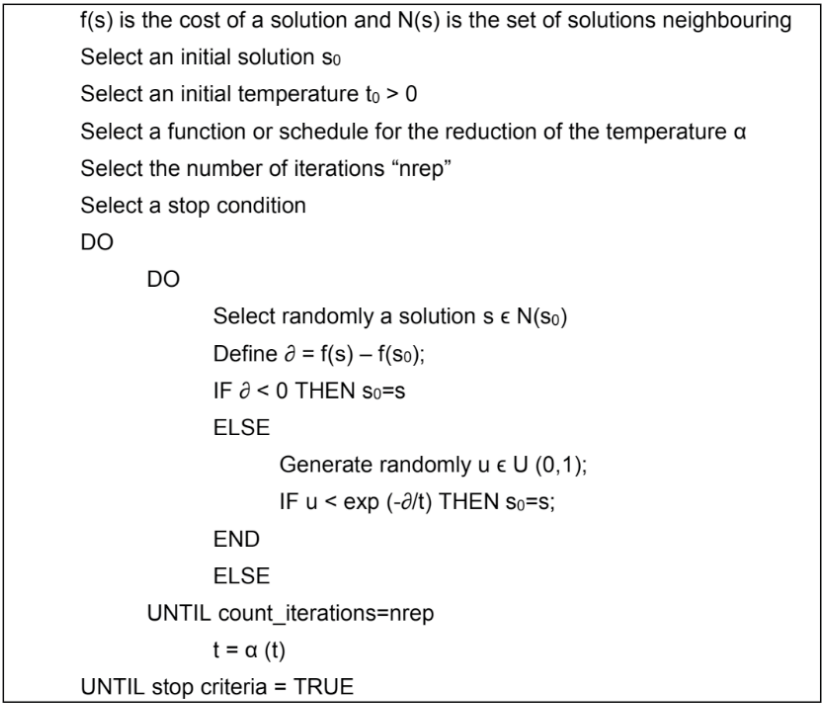
3.2 Simulated Annealing

At the beginning of the 80’s decade, Kirkpatrick et alter (1983) proposed a new heuristic for the optimum design of printed electrical circuit- The methodology that they used has an analogy with a thermodynamic process:

THERMODINAMYC SIMULATION	COMBINATORY OPTIMIZATION
States of the system	Feasible solutions
Energy	Cost
State changes	Neighbouring solution
Temperature	Control parameter
Congelation state	Heuristic solution

Table 3 Source: Kirkpatrick et alter

It can be described as a basic algorithm of simulated annealing for minimization problems as:



```
f(s) is the cost of a solution and N(s) is the set of solutions neighbouring
Select an initial solution $s_0$
Select an initial temperature $t_0 > 0$
Select a function or schedule for the reduction of the temperature $\alpha$
Select the number of iterations "nrep"
Select a stop condition
DO
    DO
        Select randomly a solution $s \in N(s_0)$
        Define $\partial = f(s) - f(s_0)$;
        IF $\partial < 0$ THEN $s_0=s$
        ELSE
            Generate randomly $u \in U(0,1)$;
            IF $u < \exp(-\partial/t)$ THEN $s_0=s$;
        END
        ELSE
    UNTIL count_iterations=nrep
        $t = \alpha(t)$
UNTIL stop criteria = TRUE
```

The best solution visited will be the heuristic solution propose by the algorithm.

3.3 Last Acceptance Hill Climbing

Last Acceptance Hill Climbing (LAHC) is a methodology proposed by Burke and Bykov (2012). The Hill Climbing algorithm "greedy" makes a comparison of the candidate solution with the immediate actual solution. The idea is making the comparison not with the actual solution if not with the one that was several iterations before. The difference is that each actual solution is employed during a back movement, not the immediate, as an acceptance criterion.

A list of previous values of the cost function is generated. The candidate solution was making a comparison with the last element of the list and is accepted if it is not worse. Once this element is accepted is included in the beginning of the list and the last element is deleted off the list. The element included in the list has the same cost as the candidate solution if it's accepted, and if it's rejected has the same value as the previous solution. So, the previous information is memorized.

The first improvement for the algorithm of LAHC was proposed by Burke and Bykov (2012) and consist of using a shifting virtual list. The elements of the list are a comparison array "Fa" of length L_{fa} (Fa= $\{f_0,f_1,f_2,\ldots.f_{Lfa-1}\}$). The start of the virtual comparison "v", in the i_{th} iteration is calculated as:

$$v = i \bmod L_{fa}$$

Where:

- mod is the remainder of the integer division.

In each iteration, the value of f_y is compared with the cost of the candidate solution and after being accepted or rejected, the new value of the cost function is assigned to $f_{y.}$ The length L_{fa} is a parameter authentical and genuine of the algorithm.

In the beginning, the search of the comparison array will contain any random initial values. Afterwards, the array will “fill in” with cost values of the searching.

The second improvement consist of accepting not only the better values than the actual solution even the those that are less than the cost function of the comparison array. So, worse movements than the actual are accepted. The in the i^{th} iteration the condition to accept the solution is:

$$C_i^* \leq C_{i-L_{fa}} \quad o \quad C_i^* \leq C_{i-1}$$

The pseudocode of the algorithm is:

```
Generate a random initial solution “s”
Calculate the value of the initial cost function $C(s)$
Specify $L_{fa}$
For all $k \in \{0.....L_{fa-1}\}$ $f_k := C(s)$
First iteration $I=0$;
Do until chosen stopping condition
Find a candidate solution $s^*$
Calculate the value of its cost function $C(s^*)$
$v := I \bmod L_{fa}$
If $C(s^*) \leq f_v$ or $C(s^*) \leq C(s)$
Then accept the candidate $(s: =s^*)$
Else reject the candidate $(s: =s)$
Insert the current value of the cost function into the fitness array $f_v := C(s)$
Increment the iteration number $I: = I+1$
end do
```

4 I EXPERIMENTAL APPLICATION TO THE OPTIMIZATION OF THE FOUNDATION OF A ROTATIVE MACHINE IN TRANSIENT AND CONTINUOUS OPERATION MODE

4.1 Foundation Model

A model of the foundation of a rotative machine under dynamic loads depending on 37 variables is optimized. Each one of the 37 variables have a range of values considered to get a solution. Each set of 37 values will be a solution.

How many solutions are there? Multiplying the 37 number of possible values of each variable between them, there are 8,12 10^{37} sets of solutions.

The proposed model by Terradez and Hospitaler (2020) for the foundation of an industrial rotative machine that Works at 3.000 r.p.m in continuous and transient operation mode has been used for the research.

The model analysed the displacement, speed and acceleration produced by the dynamic variable loads supported by the foundations:

- Vertical vibrations in the -Z axis
- Horizontal vibrations in the -X axis (sliding)
- Vibrations produced by the rocking of the machine respected a vertical axe crossing the c.o.g. of the set.

The vertical movement was studied independently of the sliding and rocking. This last two were considered coupled.

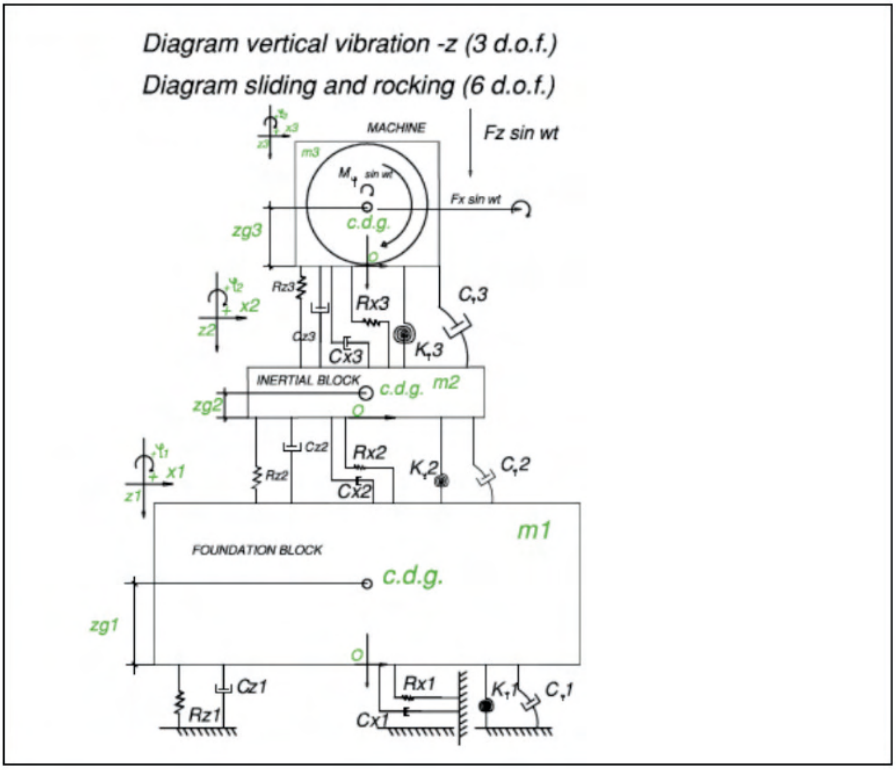


Figure 2 Diagram of the foundation model. Source: Terradez & Hospitaler

The dynamic differential equations of equilibrium of D'Alambert (Prakash and Pury, 1988) , for each one of the three solids, machine, inertial block, and foundations block were developed for the model.

4.2 D'alambert Equations

For the vertical displacement equations are:

$$\begin{pmatrix} M_1 & 0 & 0 \\ 0 & M_2 & 0 \\ 0 & 0 & M_3 \end{pmatrix} \begin{pmatrix} \ddot{z}_1 \\ \ddot{z}_2 \\ \ddot{z}_3 \end{pmatrix} + \begin{pmatrix} c_{z1} + c_{z2} & -c_{z2} & 0 \\ -c_{z2} & c_{z2} + c_{z3} & -c_{z3} \\ 0 & -c_{z3} & c_{z3} \end{pmatrix} \begin{pmatrix} \dot{z}_1 \\ \dot{z}_2 \\ \dot{z}_3 \end{pmatrix} + \begin{pmatrix} k_{z1} + k_{z2} & -k_{z2} & 0 \\ -k_{z2} & k_{z2} + k_{z3} & -k_{z3} \\ 0 & -k_{z3} & k_{z3} \end{pmatrix} \begin{pmatrix} z_1 \\ z_2 \\ z_3 \end{pmatrix} = \begin{pmatrix} 0 \\ 0 \\ F_z(t) \end{pmatrix}$$

$$[M]\,[\ddot{Z}] + [C]\,[\dot{Z}] + [K]\,[Z] = [F]$$

In which:

$[M]$ was the masses matrix

$[\ddot{Z}], [\dot{Z}], [Z]$ were the acceleration, speed and displacement matrix

$[C], [K]$ were the dynamic impedance and the stiffness matrix

$[F]$ was the load matrix

For sliding and rocking, the six equations were written in matrix mode as:

$$\begin{bmatrix} \quad M \quad \end{bmatrix}\begin{bmatrix} \ddot{a} \end{bmatrix} + \begin{bmatrix} \quad C \quad \end{bmatrix}\begin{bmatrix} \dot{v} \end{bmatrix} + \begin{bmatrix} \quad K \quad \end{bmatrix}\begin{bmatrix} x \end{bmatrix} = \begin{bmatrix} F \end{bmatrix}$$

Mass matrix [M] and accelerations matrix:

$$\begin{bmatrix} m_1 & 0 & 0 & 0 & 0 & 0 \\ 0 & m_2 & 0 & 0 & 0 & 0 \\ 0 & 0 & m_3 & 0 & 0 & 0 \\ 0 & 0 & 0 & J_1 & 0 & 0 \\ 0 & 0 & 0 & 0 & J_2 & 0 \\ 0 & 0 & 0 & 0 & 0 & J_3 \end{bmatrix}\begin{bmatrix} \ddot{x}_1 \\ \ddot{x}_2 \\ \ddot{x}_3 \\ \ddot{\varphi}_1 \\ \ddot{\varphi}_2 \\ \ddot{\varphi}_3 \end{bmatrix}$$

In which:

$[M]$ was the masses and the moment of inertia matrix

$[\ddot{X}], [\dot{X}], [X]$, $[\ddot{\varphi}], [\dot{\varphi}], [\varphi]$, were the acceleration, speed and displacement matrix for sliding and rocking.

$[C], [K]$ were the dynamic impedance and the stiffness matrix for sliding and rocking.

$[F]$ was the load matrix, strength, and momentum matrix for sliding and rocking.

The equations were integrated in the time domain using the Newmark's β methodology [11] with these parameters:

- β = 1/4
- Δt = 0.001 s.

4.3 Other Considerations About The Model

Displacements, speeds, and accelerations were calculated for the transient starting operation mode and continuous operation mode. Parameters of the start-up ramp were defined to limit the vibrations on the transient operation mode. To avoid the resonance frequency of the system during the transient starting operation the amplitude of vibration of the machine was limited.

The set machine-inertial block-foundation block was working inside the elastic zone, even the soil. The plastic calculation was not considered.

The machine rested over the inertial block of steel concrete, ant this, over a foundation steel-concrete block. Between, special shock absorbers and insulation pad mattress connected them. Stiffness and dumping of the set-off shock absorbers and the mattress were calculated for vertical vibration, sliding and rocking.

Foundation, a continuous steel-concrete block uniform was embedded in the soil. Soil was uniform, elastic, continuous and homogeneous. Dynamic characteristics of the soil, stiffness and did not change with the frequency of the dynamics loads.

The connection between the soil and the foundations was modelled with a stiffness and dumping parameters for vertical vibration, sliding and rocking.

The stiffness and dumping parameters were considered as lumped parameters on the centre of gravity of each one of the solids (zg1-xg1, zg2-xg2 y zg3-xg3) with nine freedom degrees (z1, z2 y z3-x1, x2 y x3 – ϕ1, ϕ2 y ϕ3).

4.4 Sloping RAMP-UP

A rump-up to start the operation of the machine was described as:

$$\omega\ (t) = \omega_{max}\ [(1\text{-}(1 - (t/t_m)^p]^{1/q}$$

In which the nominal speed parameter is:

Parameter	Description	Value
ω_{max}	Nominal speed in rad/s	100 rad/s

The three operation variables were:

Variable	Description	Values
p	Variable of the equation	1,2,3,4
q	Variable of the equation	1,2,3
tm	Time to get the machine nominal speed.	180-360 s.

4.5 Solutions For Each Set Of Variables – Cost Function

To analyse the set of solutions of the foundation a cost function was defined. Cost function was a no continuous function, a discrete function, and so, the analytic methodology was not possible to be used to get the optimum.

Let S(X) a set of solutions, where:

- X was an array 1x 37 that € S(x)
- x was a solution.

Cost(X) was defined as:

$$Cost(X) = \sum_{i=1}^{20} c_i(x_i)$$

Cost function was a sum of 20 addend depending on 37 variables X_i. Objective was to minimize the cost function to get the best local minimum.

5 I EXPERIMENTAL PLAN

The three algorithms had been implemented in three computer codes developed with MATLAB. The computer used was:

- 4 GB RAM
- Intel Core i5 processor
- O.S. Windows 7 - 64 bits
- And the code:
- MATLAB R-2016b

The number of experiences run were:

- For the DLS algorithm were made a total of 700 experiences.
- For the S.A. algorithm were made a total of 52 experiences.
- For the LAHC algorithm were made a total of 50 experiences.

For all the algorithm a stop condition was proposed: when after a number of solutions, no feasible are tested from the actual solution and no new solution was found.

The heuristic methodologies by its “random” characteristic produce a different solution each time that the algorithm is implemented. The first question that was considered when a heuristic is employed is: how many times must be implemented the heuristic to get an optimal solution with enough precision? The second question to answer was, how far are we from the optimal global solution?

Paya-Zaforteza, Yepes, Gonzalez Vidosa y Hospitaler (2010) based on the “extreme value theory” and adjusting to a Weibull distribution of three parameters (scale, shape and location) the set of optimal values calculated for a structure example with the heuristic Simulated Annealing established the value of the theoretical optima solution and the minimum number of times that the algorithm must run to get a reliable value of the optimal of the cost function.

Authors calculated 1000 optimal solutions of the cost function for the “example structure” with S.A. Adjusting the set of solutions to a Weibull Distribution of three parameters. The location parameter shows the vicinity of the minimum to the minimum global theoretical value. They deduced that the location parameter it’s enough reliable as the global minimum when you adjust the distribution only with 14, 16 or 18 optimum values, depending on the heuristic employed and the stop criteria. 1000 experiences took a long runtime, and, with only 18 experiences, a reasonable optimum was obtained.

Fitting to a 3 parameters Weibull distribution was implemented with the application “MINITAB Statistical Software 18”.

6 | RESULTS

6.1 DLS

700 times run the heuristics of DLS implemented stating with a feasible random

solution. The stop criteria established was that when after 1.000 solutions no feasible are tested from the actual solution and no new solution was found the program stop.

The statistical parameters of the set of values obtained is described in table 4.

	COST FUNCTION	RUNTIME
Mean value	2 123 716,22 €	2 627,57 s
Minimum value	1 767 800,12 €	291,35 s
Maximum value	3 215 384,07 €	14 028,29 s
Standard deviation	287 713,53 €	1.837,94 s
Mode	2 011 040,92	291,35 s

Table 4 Statistical parameters for DLS. Source: authors

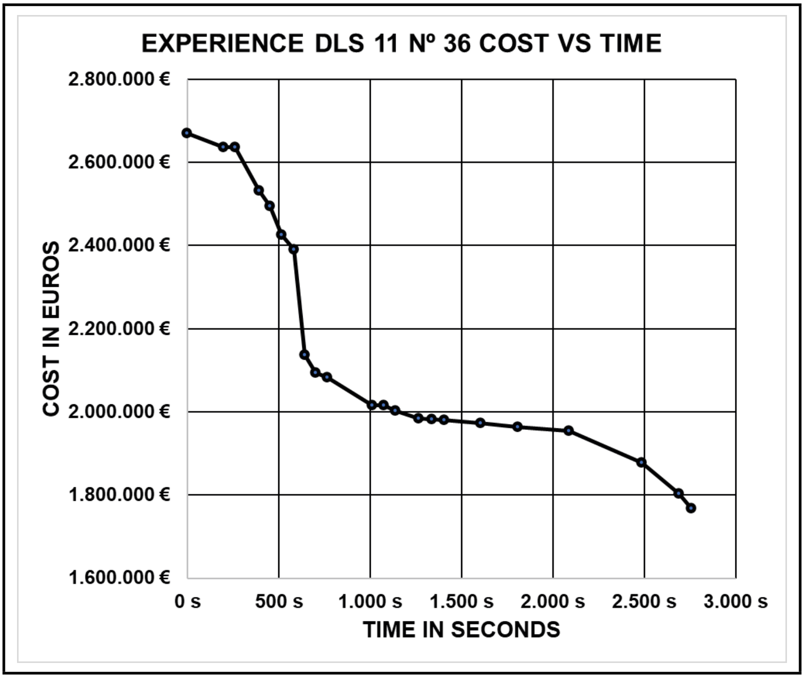


Figure 3 Graphic experience 11 DLS. Source : authors

In the graphic of figure 3, the black line of the 11 experience, with number 36 in the legend shows how the algorithm got the minimum value of 1.767.800,12 €. Each one of the black points displayed represent the moves from one feasible solution to another feasible solution of less value. Algorithm did a total of 21 moves till getting the best value.

The fitting of the set of optimal solutions to a three parameters Weibull distribution is shown in figure 4.

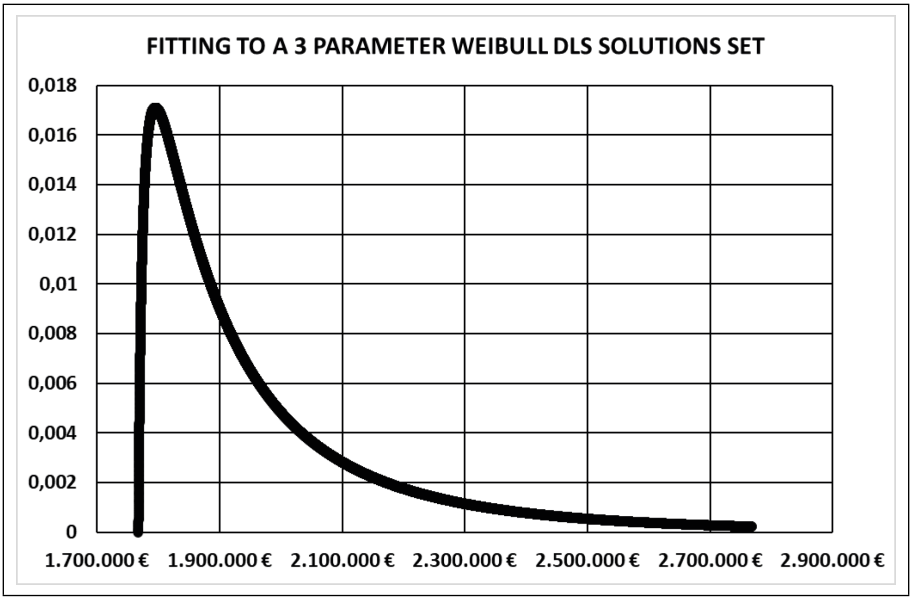


Figure 4 Fitting DLS set of solutions to a Weibull 3 parameters distribution. Source: authors

6.2 SA

52 optimization experiences using the heuristic of Simulated Annealing run with the MATLAB code. The statistical parameters of the set of values obtained is described in table 5.

	COST FUNCTION	RUNTIME
Mean value	1 951 560,772 €	43 733,70 s
Minimum value	1 797 327,12 €	2 135,53 s
Maximum value	2 627 625,13 €	89 334,26 s

Table 5 Statistical results parameters for SA. Source: authors

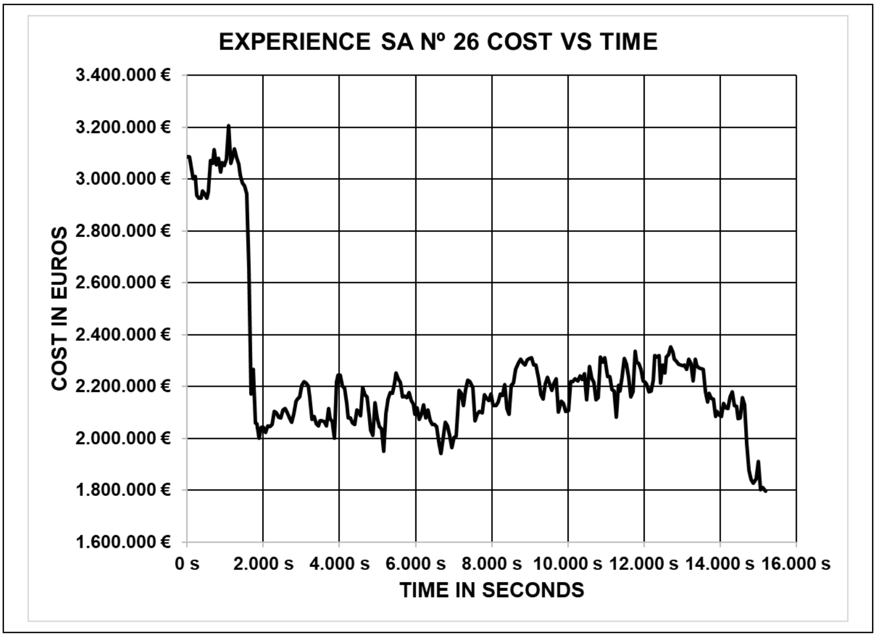


Figure 5 Graphic experience 26 SA. Source: authors

The graphic of figure 5 shows, how in the 26th experience, the algorithm achieved the minimum value of 1.797.327,12 €. Algorithm accepted solutions with a value of the cost function worse than the actual solution until the last transition to the minimum, where the stop criteria blocked it. The fitting of the set of optimal solutions to a three parameters Weibull distribution is shown in the figure 6.

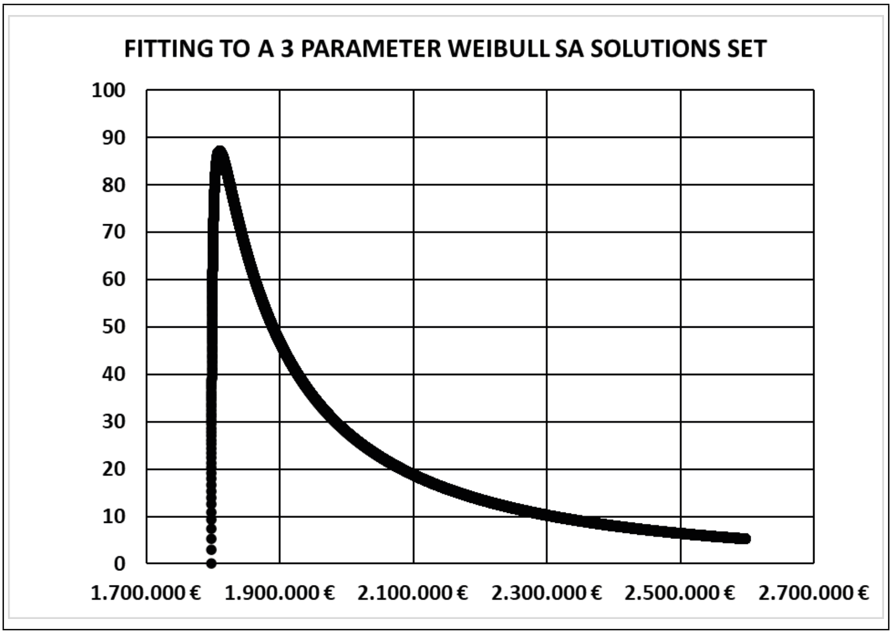


Figure 6 Fitting SA set of solutions to a 3 parameters Weibull distribution. Source: authors

6.3 LAHC

A set of 50 experiences with a length of the fitness array Fa, (L_{Fa}) = 500 run with the MATLAB code. The values of the fitness array were extracted from a set of 2.000 random feasibly solutions. The statistical parameters of the set of values obtained is described in table 6.

	Minimum	**Mean**	**Maximum**
Cost	1.806.871 €	2.006.850 €	2.496.634 €
Runtime	270.41 s	35.758 s	99.263
Transitions	6	500.66	1.373

Table 6 Statistical parameters for LAHC. Source. authors

Experience number 548S of figure 6 achieved the best minimum value of the cost function. In the graphic is shown the evolution of the heuristic to achieve the minimum of the cost function until the heuristic was blocked by the stop condition.

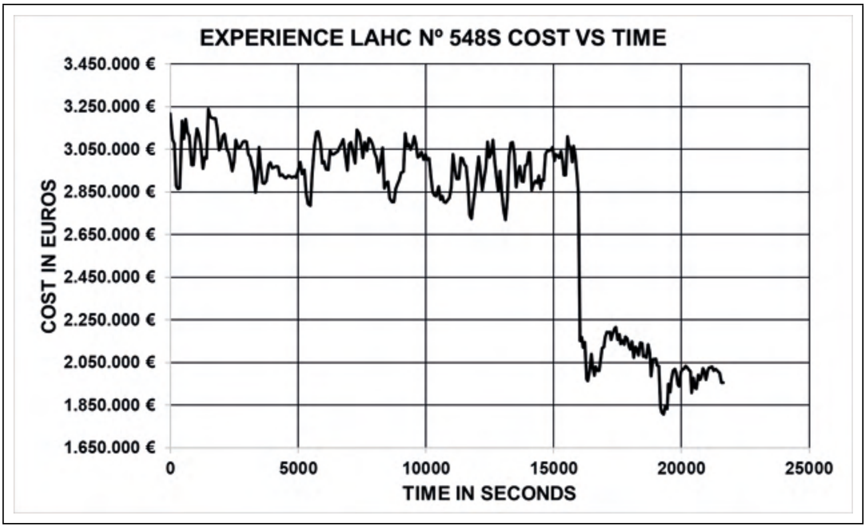


Figure 7 Graphic experience 548S LAHC. Source: authors

The fitting of the set of optimal solutions to a three parameters Weibull distribution is shown in figure 8.

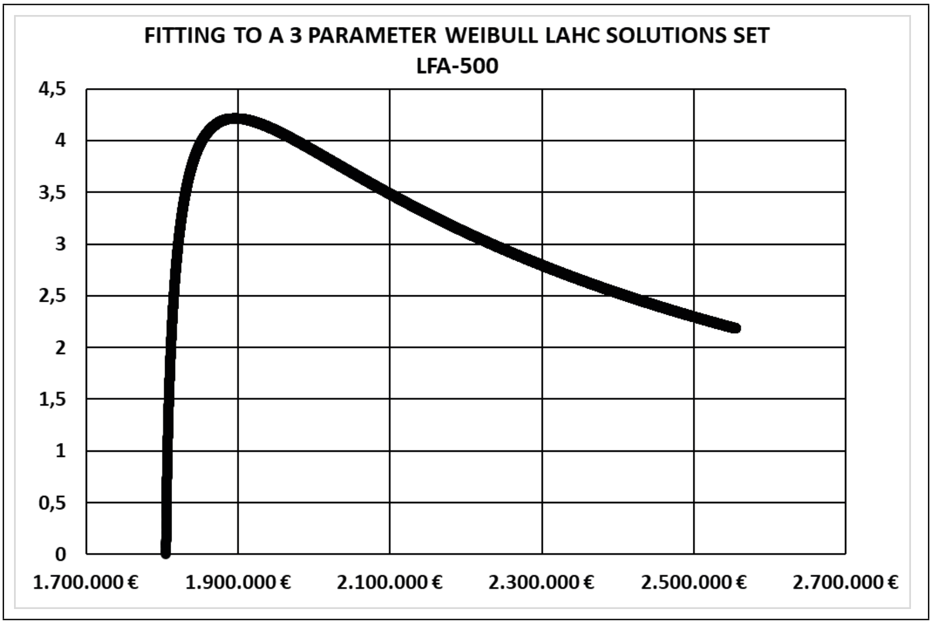


Figure 8 Fitting LAHC set of solutions to a Weibull 3 parameters distribution Source: authors

The values of the variables of best optimal solutions of the foundation for the rotary machine for each heuristic are shown in Table 7.

Var.name	DLS	SA	LAHC
a2	16,4 m	16,4 m	16,4 m
b2	8,2 m	8,4 m	8,6 m
c2	1,2 m	1,2 m	1,6 m
a1	16,6 m	16,8 m	17,2 m
b1	8,4 m	9 m	9,6 m
c1	2,6 m.	2 m	1,8 m
eb	60%	50%	40%
p	3	2	4
q	1	1	2
nrz3	62	66	60
nrz2	60	60	60
ndz3	44	42	42
ndz2	44	48	42
nrx3	40	42	46
nrx2	40	42	42
nrx1	40	40	40
ndx3	40	42	42
ndx2	40	40	40
ndx1	22	20	22
tr	255	230	235
biz3	1	1	2
biz2	3	1	2
biz1	4	2	2
bix3	2	4	4
bix2	2	2	2
bix1	3	3	3
airpz3	1	1	1
airpz2	1	1	1
airpx3	1	1	1
airpx2	1	1	2
airpx1	1	2	1
pbiz3	90%	40%	10%
pbiz2	0%	10%	50%
pbiz1	60%	70%	60%
pbix3	80%	0%	20%
pbix2	90%	50%	10%
pbix1	30%	70%	30%

Table 7 Variables values of the best optimal solution for DLS, SA and LAHC. Source: authors

6.4 Analysis Of The Vibrations Constrains Of The Solutions.

Inside the set of solutions three variables related to the start-up are selected by the algorithm of each heuristic. Results are:

Var.name	DLS	SA	LAHC
p	3	2	4
q	1	1	2
tr	255 s.	230 s	235 s.

Table 8 Variables related to the star-up rump for DLS, SA and LAHC. Source: authors

ts graphic representation is in figure 9.

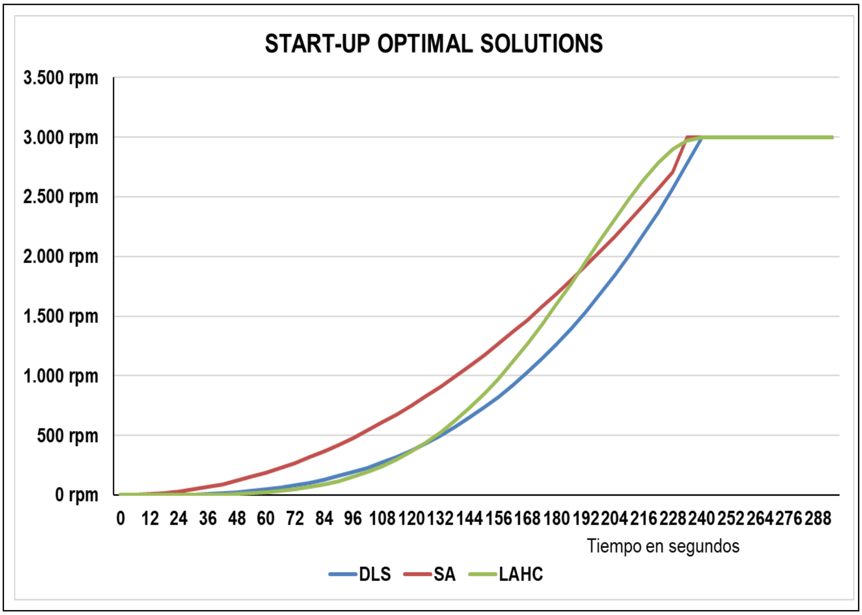


Figure 9 Start -up ramp optimal solutions. Source: authors

The maximal vibrations for the -x direction are described in table 9.

	xp3	xt3	vxp3	vxt3	axp3	axt3
1*	**1,05 E-04**	**1,05 E-02**	**4,50 E-03**	**4,50 E-01**	**9,80 E-01**	**9,80 E+01**
DLS	7,07 E-06	2,59 E-05	2,22 E-03	4,60 E-03	6,99 E-01	8,17 E-01
SA	6,89 E-06	2,20 E-05	2,16 E-03	4,00 E-03	6,80 E-01	7,70 E-01
LAHC	6,33 E-06	4,19 E-05	1,99 E-03	6,85 E-03	6,25 E-01	1,12 E+00

Table 9 Vibrations in transient and permanent operation mode x direction. Source: authors.

1* Maximum value constrain

The graphic representations of the displacement, speed and acceleration for the -x direction are in figures 10,11 and 12.

Red horizontal lines represent the constrains for the permanent mode operation. The first vertical line represents the value of the “tr”, time to get the nominal speed.

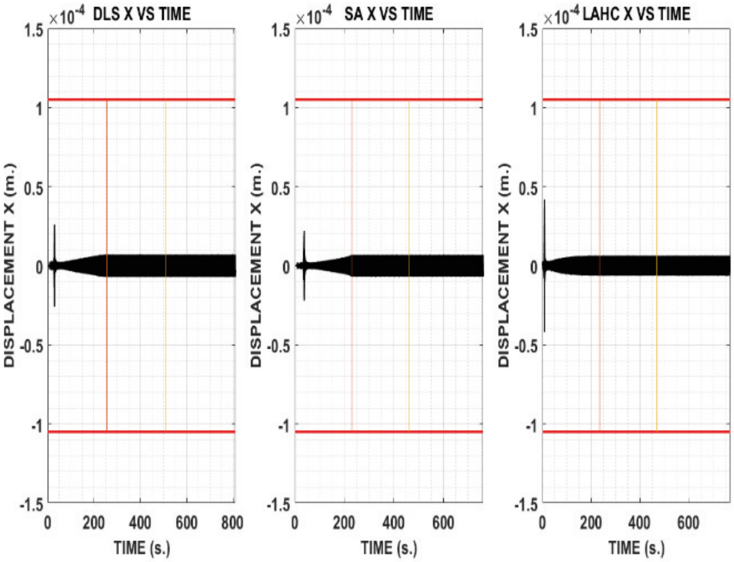


Figure 10 Displacement x vs time optimal solutions. Source: Authors

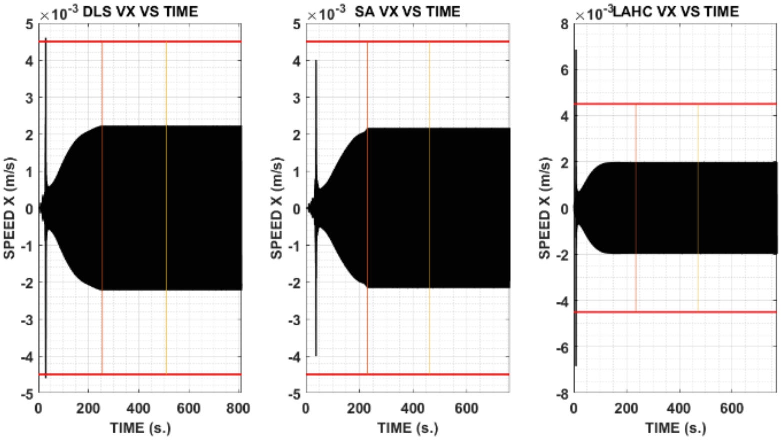


Figure 11 Speed x vs time optimal solutions. Source: authors

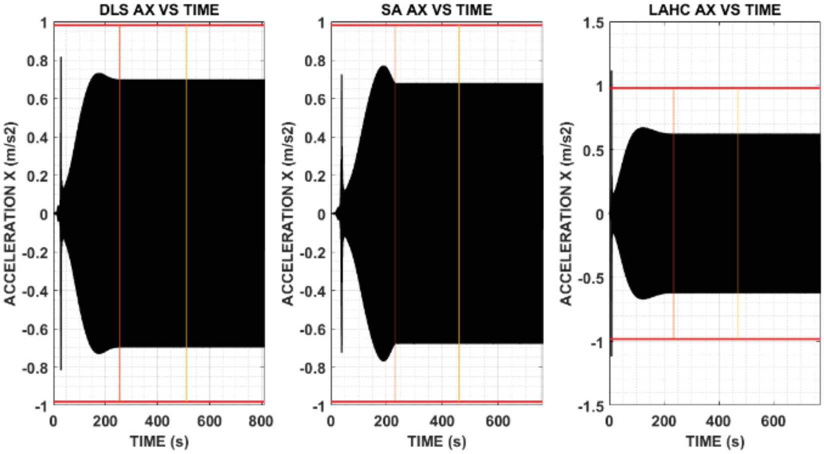


Figure 12 Acceleration x vs time optimal solutions. Source: authors

As the graphics shown, the solution got it with DLS and SA heuristic, maximal vibrations in transient and permanent mode for -x direction are under constrains applied in transient and permanent operation mode.

The maximal vibrations for the -z direction are described in table 10.

	zp3	**zt3**	**vzp3**	**vzt3**	**azp3**	**azt3**
1*	**1,05 E-04**	**1,05 E-02**	**4,50 E-03**	**4,50 E-01**	**9,80 E-01**	**9,80 E+01**
DLS	1,20 E-05	1,19 E-05	2,49 E-03	2,49 E-03	7,82 E-01	7,82 E-01
SA	1,27 E-05	1,22 E-05	2,41 E-03	2,41 E-03	7,58 E-01	7,72 E-01
LAHC	6,58 E-05	6,72E-05	2,43 E-03	2,43 E-03	7,63 E-01	7,64 E-01

Table 10 Vibrations in transient and permanent operation mode z direction. Source: authors

1* Maximum value constrain

The graphic representations of the displacement, speed and acceleration for the -x direction are in figures 13,14 and 15.

Red horizontal lines represent the constrains for the permanent mode operation. The first vertical line represents the value of the “tr”, time to get the nominal speed.

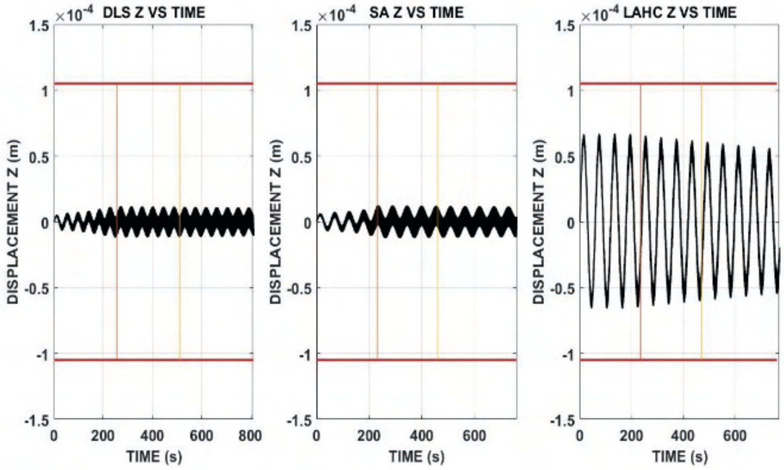


Figure 13 Displacement z vs time optimal solutions Source: authors

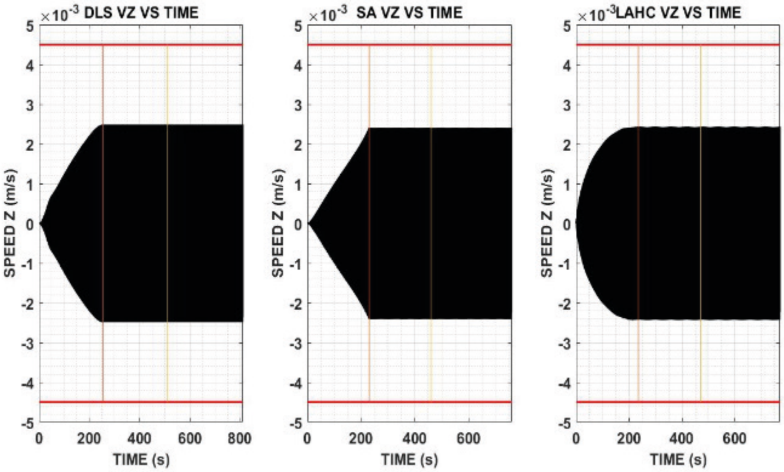


Figure 14 Speed z vs time optimal solutions. Source: authors

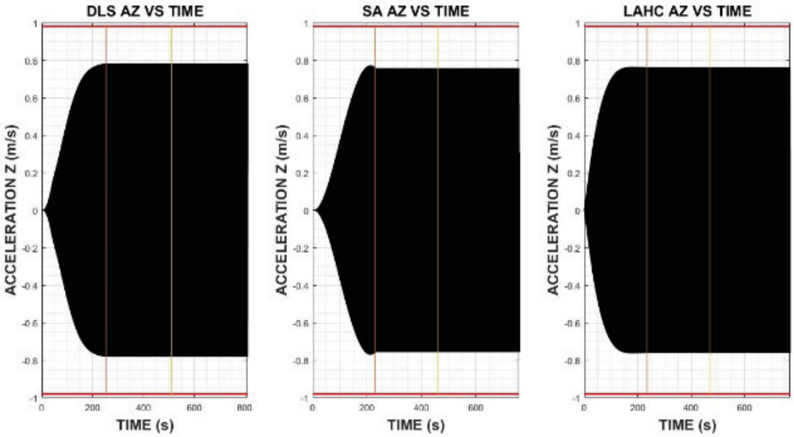


Figure 15 Acceleration z vs time optimal solutions. Source: authors

As the graphics shown maximal vibrations in transient and permanent mode for -z direction are under constrains applied in transient and permanent operation mode for all the solutions.

7 I CONCLUSIONS

Three heuristics minimized the cost function and got optimum solutions for the foundation of the machine. The three heuristics used the same mechanism of variable neighbouring search of one point. SA and LAHC accepted worse moves to get a better local minimum in the search of the global optimum. Comparing the fitting to a three-parameter Weibull Distribution of each set of solutions was on table 11 and 12.

	Location parameter	% on l-p-	Min. value	% on LAHC	Mean value	Max value
DLS	1 767 456 €	1%	1 767 800 €	1,02%	2 123 716 €	3 215 384 €
SA	1 797 043	1%	1 797 327 €	1,01%	1 951 560	2 672 605 €
LAHC	1 805 185 €	1%	1 806 871 €	0%	2 006 850 €	2 496 634 €

Table 11 Comparison fitting set of solutions to a 3 parameters distribution Weibull with respects to LAHC. Source: authors

Source: Authors

	Minimum time	Mean time	% on SA	Max time	Experience number	Max value
DLS	291 s	2 627 s	6,01%	14 028 s	700	1 838 900s
SA	2.135 s	43 733 s	0%	89 334 s	52	2 274 116 s
LAHC	270 s	35 758 s	81,8%	99 263 s	50	1 787 900 s

Table 12 Comparison mean, max and minimum value set of solutions respects to SA.

Source: authors.

- The fitting to a three-parameter Weibull distribution of the set of optimal solutions permitted knowing the neighbouring to the global minimum. Three distributions were adjusted with a difference of only 1% between the best local optimum and the theoretical global optimum, represented by the location parameter.
- The DLS algorithm expends less runtime, it did not accept worse moves anyway. It took a mean of 2.627 seconds per each runtime experience. The less runtime allowed to do more experiences and using the heuristic methodology got a better local minimum.
- Simulated Annealing was the slowest algorithm of the three proposed and expended more runtime to do the fifty-two random experiences. The mean runtime was of 43.733 s.
- LAHC is faster than SA. The mean runtime was of 35.758 s. per experience. It took 14 times more runtime than DLS and 18,2 % time less than S.A.
- The foundation calculated reduces the vibrations transmitted to the machine under the constrains implemented, displacement according to ISO 10816-1995, speed according to VDI 2056 Norm and acceleration according to Blake chart.
- The selection of the p-q start up rump and the design of the foundations reduces considerably the horizontal and vertical displacements in the transient and the permanent operation mode not being critical in the design.

Variable neighbouring searching heuristics are efficient for the searching of the optimal foundation. Other metaheuristics based on natural process (ant, bees, genetics, etc) can be applied to get the global minimum of the COST function and the best solution.

APPENDIX 1 FOUNDATION MAP

The map of the foundation is shown in this graphic.

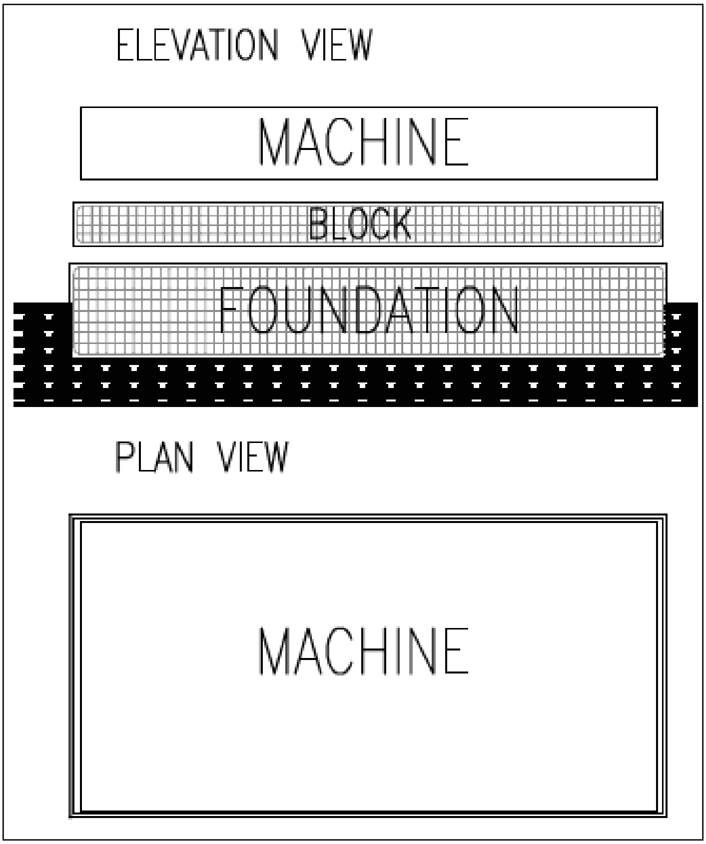


Figure 16 Map of the plan and elevation view of the set foundation, inertial block, and machine for DLS optimal. Source : authors.

APPENDIX 2 DESCRIPTION OF VARIABLES

Var.	Description	Value/Units.
a_2	Length of the inertial block	m.
b_2	Wide of the inertial block	m.
c_2	Height of the inertial block	m.
a_1	Length of the foundation block	m.
b_1	Wide of the inertial block	m.
c_1	Height of the foundation block	m.
e_b	Embedded depth of the foundation block	%
n_{rz3}	Number of springs between the inertial block and foundation block in the -Z axis.	units
n_{rz2}	Number of springs between the machine and the inertial block in the -Z axis.	units

n_{dz3}	Number of shock absorbers between the inertial block and the foundation block in the -Z axis.	u.
n_{dz2}	Number of shock absorbers between the machine and the inertial blocks in the -X axis.	u.
n_{rx3}	Number of springs between the inertial block and the foundation block in the -X axis.	u.
n_{rx2}	Number of springs between the inertial block and the foundation block in the -X axis.	u.
n_{rx1}	Number of springs in the block foundation in the -X axis.	u.
n_{dx3}	Number of shock absorbers between the machine and the inertial block in the -X axis.	u.
n_{dx2}	Number of shock absorbers between the inertial block and the block foundation in the -X axis.	u.
n_{dx1}	Number of shock absorbers in the block foundation in the -X axis	u.
pbix1	Percentage of the surface with isolation pad in the walls of the foundation block in the -X axis.	% - 0-100%
pbix2	Percentage of the surface with isolation pad in the inertial block in the -X axis	% - 0-100%
pbix3	Percentage of the surface with isolation pad in the machine support in the -X axis	% - 0-100%
pbiz1	Percentage of the surface with isolation pad under the foundation block in the -Z axis	% - 0-100%
pbiz2	Percentage of the surface with isolation pad in the inertial block in the -Z axis	% - 0-100%
pbiz3	Percentage of the surface with isolation pad in the machine support in the -Z axis	% - 0-100%
b_{iz3}	Type of isolation pad between the machine and the inertial block in the axis -Z	1,2,3,4
b_{iz2}	Type of isolation pad between the inertial block and the block foundation in the axis -Z	1,2,3,4
b_{iz1}	Type of isolation pad between the inertial block foundation and soil in the axis -Z	1,2,3,4
b_{ix3}	Type of isolation pad between the machine and the inertial block in the axis -X	1,2,3,4
b_{ix2}	Type of isolation pad between the inertial block and the block foundation in the axis -X	1,2,3,4
b_{ix1}	Type of isolation pad between the inertial block foundation and soil in the axis -X	1,2,3,4
airpz3	Type of shock absorber between the machine and the inertial block in the axis -Z	1,2,3
airpz2	Type of shock absorber between the inertial block and the block foundation in the axis -Z	1,2,3
airpx3	Type of shock absorber between the machine and the inertial block in the axis -X	1,2,3
airpx2	Type of shock absorber between the inertial block and the block foundation in the axis -X	1,2,3
airpx1	Type of shock absorber between the inertial block foundation and soil in the axis -X	1,2,3

Table 13 List of variables. Source: authors

REFERENCES

ACI Committee 351**, Foundations for Dynamic Equipment**, ACI 351.3R-04, American Concrete Institute, USA, 2004.

Anyagebunam, A.J., **Minimum foundation mass for vibration control, Journal of Geotechnical Engineering**, American Society of Civil Engineers (ASCE), Reston, February 2011, 6 pp.

Appleby, J.S, Blake, D.V. y Newman, E.A., **Techniques for Producing School Timetables on a Computer and their Applications to Other**, The Computer Journal, Vol.3 Issue 4, 1961, pp. 237-245

Arya, Suresh, O'Neill, Michael, y Pincus, George, **Design of Structures and Foundations for Vibrating Machines**, Houston, Gulf Publishing Company, 1979, 193 pp.

Burke, Edmund K. and Bykov, Yuri; **The Late Acceptance Hill-Climbing Heuristic**, Technical Report CSM-192, ISSN 1460-9673, June 2012, 19 pp.

Calavera, J., **Calculo de Estructuras de Cimentación**, 4th edition, INTEMAC, Madrid , 2000, 529 pp.

Chowdhury, Indrajit y Dasgupta, Shambhu P., **Dynamics of Structure and Foundations**, London, CRC Press, 2009, 2 vol., 861 pp.

ISO NORM 10816-1995, Mechanical vibration – **Evaluation of the Vibration of a Machine in no Rotative Parts, International Organization for Standarization**.

Kirpatrick, S.; Gelatt, C.D.; Vecchi, M.P.;**Optimization by Simulated Annealing**, Science, New Series, Vol. 220 Issue 4598, 1983, pp. 671-680.

Lysmer, J. y Richart, F.E., **Dynamic response of footing to vertical loading, Journal of the Soil Mechanics and Foundations Division**, Berkeley, American Society of Civil Engineers (ASCE), 1966, Vol. 92, pp. 65-91.

Newmark, N.M., **A Method of Computation for Structural Dynamics, Journal of Engineering Mechanics Division (ASCE)**, 1959, Vol 85. Nº EM3, pp 67-94.

Paya-Zaforteza, I., Yepes, V., Gonzalez-Vidosa, F. y Hospitaler, A., **On the Weibull Cost Estimation of Building Frames Designed by Simulated Annealing**, Mecanica, Springer Science+Business, Febrero 2010, vol. 45, pp. 693-704.

Prakash, Shamsher y Puri, Vijay K., **Foundations for Machines: Analysis and Design**, Massachusetts, John Wiley & Songs, 1988, 656 pp

Richart, F.E., Woods, R.D. y Hall, J.R., **Vibration of Soils and Foundations**, Prentice-Hall, New Jersey, 1970, 414 pp.

Rodriguez, Juan Luis, Alemán Mercedes, Garcia Benítez Lazaro and Iribe-Adundi Juan Jose, **Problemas de Operación Durante el Arranque de un Bloque Energético de 330 MW**., Matanzas, Universidad de Matanzas, 15 pp, 2010.

Sienkiewicz, Z. y Wilczynski, B., **Minimum-weight design machine foundations under vertical load**, Journal of Engineering Mechanics, American Society of Civil Engineers (ASCE), Reston, 1993, vol. 119, nº 9, pp. 1781-1797.

Sienkiewicz, Z. y Wilczynski, B., **Shape optimization of a dynamically loaded machine foundation coupled to a semi-infinite inelastic medium, Structural Optimization**, Springer-Verlag, Berlin 1996, vol. 12, pp. 29-34.

Silva, Marcelo, Arora, Jasbir S., Swan Colby, C. y Reyolando, M.L.R.F., **Optimization of Elevated Concrete Foundations for Vibrating Machines**, Journal of Structural Engineering, American Society of Civil Engineers (ASCE), 2002, vol. 128, nº 11, pp. 1470-1479

Taillard, E.D.; Gambardella, Luca M.; Gendreau, M and Potvin, Jean Yves, **Adaptative Memory Programming: A unified view of Metaheuristics**, European Journal of Operational Research nº 135, Elsevier, 2001, pp.1-16.

Terrádez Marco, Juan L. and Hospitaler Perez, Antonio, **A Methodology for the Calculation of the Foundation of a Rotary Machine Supporting Dynamic Loads Including the Transient Starting**, Anales de Edificación, Vo, 6, Nº1 12-23,2020, Doi:10.20868/ade.2020.4450

VDI 2056 NORM, 1964, **Standards of Evaluation for Mechanical Vibrations of Machines**.

ÍNDICE REMISSIVO

Atena
Editora
Ano 2021

www.atenaeditora.com.br
contato@atenaeditora.com.br
@atenaeditora
www.facebook.com/atenaeditora.com.br

Ciência, tecnologia e inovação:

2

Fatores de progresso e de desenvolvimento

Atena
Editora
Ano 2021

www.atenaeditora.com.br
contato@atenaeditora.com.br
@atenaeditora
www.facebook.com/atenaeditora.com.br

Ciência, tecnologia e inovação:

2

Fatores de progresso e de desenvolvimento