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CREATING INTEGRATED SYSTEM BETWEEN LIFECYCLE QUALITY MANAGEMENT AND FINITE ELEMENT ANALYSIS TO IMPROVE TYPICAL TURBINE BLADE DESIGN AS A CASE STUDY

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ABSTRACT

This article proposes a process to integrate efficiently the Finite Element Analysis in the Quality Life-Cycle Management in order to use the simulation engineering in analyzing and improving the design of one industrial part. In addition, a new flowchart has been created to enter the data resulted from Numerical Analysis using ANSYS code in QLM process for a typical turbine blade (as a case study) to show the practical steps of design validation in digital method. This paper prepares the base to simulate a complex industrial assembly in integrated FEA-QLM process as a future work.

KEYWORDS: Finite Element Analysis, Simulation, Digital Manufacturing, Life-cycle Quality, Management

1. Introduction

Quality assurance and efficient management are basic titles for any successful industry in our days, furthermore using computer simulation and Numerical analysis should the keys to obtain these goals in global market. There is a big challenge nowadays to integrate the simulation engineering in management process and we are trying in this paper to promote an integrated process which combines the FEA results and data in QLM process using a simple case study to show the practical steps in order to optimize the design and create a valuable database for production management. New approach in Quality management can be seen now by using simulation to improve life-cycle quality for any type of products, which leads us more and more toward hybrid industry and automation design [1]. In addition, the FEA-QLM flowchart, which has been created, helps the engineer to control all quality-oriented activities.

2. Quality Lifecycle Management (QLM)

2.1. QLM definition

Quality lifecycle management is multidimensional process which provides solutions to manage all aspects in product quality and reliability; however, this process has to start early in product development and design and continuously be applied in following levels like products, validation, quality assurance etc.

Quality lifecycle management (QLM) promotes information about quality process and assures product's reliability using methods that are fully integrated into the product development lifecycle and highly visible to all personnel with a stake in product quality [2].

Quality management must connect all activities related to quality in one procedure, easy to follow and control, from design level to cost planning and risk estimation. Figure 1 shows the QLM continues cycle which work to improve activity in the production line [3].

As we see in Fig. 1 QLM will accompany the designer and manager in each step during the production, so the lifecycle of the product will be controlled step by step to minimize the errors and assure that we will have production driven by quality. Indeed, we need criteria for every step, for example designers will have criteria to which part needs more support and improvement, test engineers have criteria to define which character must be tested, manufacturers have to know which aspect will be controlled in production line, and service section will have a clear plan to do maintenance and repairing respecting to product performance and properties [3].

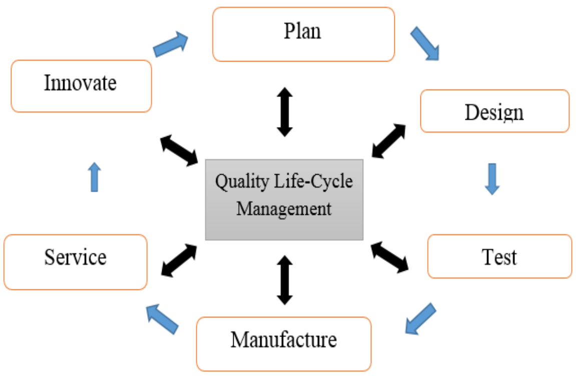


Fig. 1. *QLM process*

2.2. QLM Challenges

Achieving quality in production process will meet many challenges because there is no ideal environment or system for quality management; however, QLM is designed to overcome these challenges during the lifecycle of the product if it is applied in right way. Basic challenges in production process are as following:

1 - quality of each specific product must be defined by the producer, because every product has special purpose with quality concept, conditions and criteria.

2 - the need of gathering, organizing, documenting and promoting quality information for all the production levels and providing the ability to access to this information for all responsible staff.

3 - enroll quality rules in the management system and production process to have integrated procedure of quality [4].

3. An Overview of Numerical Analysis

Numerical Analysis is the method to use numerical approximation for equations in a mathematical analysis. Numerical calculation creates a great chance to use simulation engineering for all kinds of engineering projects using the high power of computers in our days. This analysis concentrates on obtaining approximate solutions for our problem with an acceptable margin of errors [5].

The main idea of numerical analysis is to study the physical model of our problem and obtain a suitable mathematical model that describes the problem and can control the variables and push forward for solution. Mathematical model means use approximate functions to change differential equations to integral algebraic ones, so we can use the power of computers to solve the new matrix of equations.

Based on computational discretization methods to divide geometry and enter boundary conditions we can discuss three basic methods for numerical analysis:

1 - Finite Element Method (FEM).
2 - Finite Volume Method (FVM).
3 - Finite Difference Method (FDM).

3.1. FEM

FEM is a computational method to divide the geometry (CAD model) into small finite-sized elements in simplest possible shape, the name of this network of elements is Mesh and we call the contacts points between elements Nodes. In this method dependent values are stored at the elements and nodes.

3.2. FEM basics

This method is the most difficult to apply however it has the best accuracy especially in complex CAD models, because of that we will concentrate on this method and its basics and applications.

For applying FEM for engineering model, we need first to specific the physical governing equations which control the model, then to obtain mathematical model we need to change PDE to integral equations using approximate functions (linear, nonlinear, quadratic polynomial); [See 3]. Using this function and creating the Mesh which contains elements and nodes with specific number of Degree of Freedom (DOF^{s}) lead us to end up with a large sparse matrix equations system that can be solved by power calculation of computers [5].

3.3. FEA Industrial Applications

Nowadays engineers can use FEA to simulate almost all engineering problems and analysis (structural analysis, heat transfer, flux and fluid dynamics, electromagnetic, etc.).

In machine manufacturing field we can mainly distinguish three basics applications:

1 - design optimization.

2 - test quality and reliability for mechanical parts.

3 - improve manufacturing Process for mechanical assembly [5, 6].

4. Integrated FEA and QLM system

4.1. FEA-QLM Flowchart

In this paper a new efficient system is designed to integrate FEA process in QL - Management and got benefits from both to improve the quality.

It is true that the basic step in any quality procedure is to collect data and analyze them in best possible way, so this system relays on gathering data from both FEA and QLM processes and create an effective data-base which helps the designers and managers to push over the product's quality and reliability forward in lower cost and time.

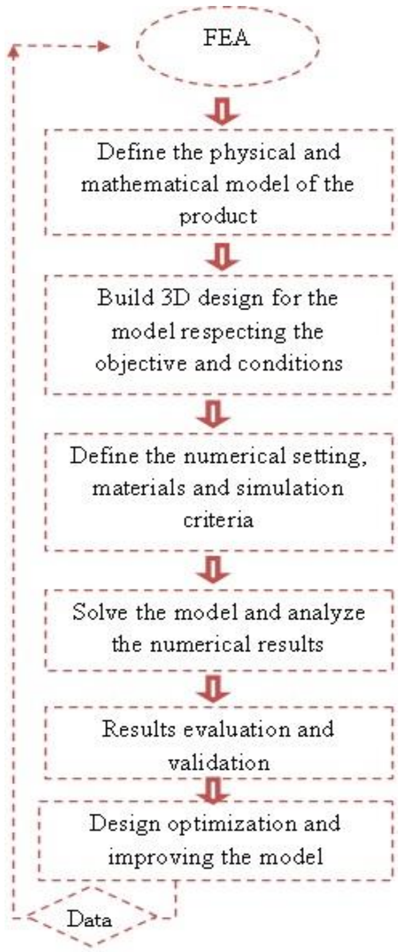


***Fig. 2.** FEA flowchart*

Fig. 2 shows FEA process, which we can use for every simulation we want, and this process creates a valuable source of data for the designer engineer. However, in Fig. 3 we can see the flow chart which has been created in this paper to show an integrated system between FEA process and QLM flowchart. [5, 7]. As we notice from Fig. 3, the FEA will enter the QLM process in design level and will provide a source of numerical results, which will be return to the process in Test level.

4.2. FEA-QLM cycle

FEA provides very good source of data to the designer about the product's behavior under many scenarios of loading and working, furthermore helps them to analyze data and evaluate the results. In engineering projects testing the prototype models for any products needs a big budget and time, while by using numerical analysis and simulation, the designer can create a virtual environment very similar to reality and test the product in many cases of service [8].

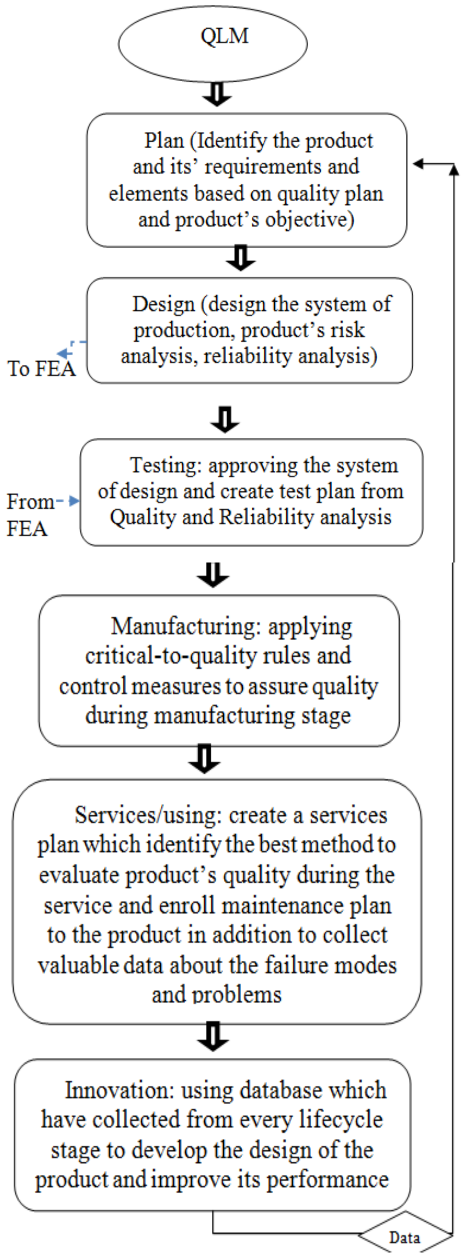


***Fig. 3.** FEA-QLM integrated flowchart-insert the FEA database in Design and Testing levels during the Quality Life-cycle Management*

By integrating FEA and QLM together we can create a new Data-cycle process which is very efficient in any quality management system. Fig. 4

displays the Data-Cycle which collects data from both real environment and virtual environment.

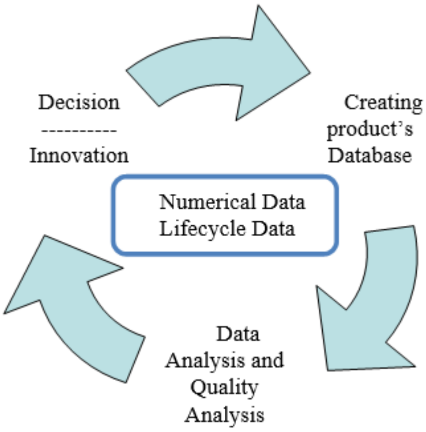


Fig. 4. *FEM-QLM Data cycle*

By using numerical data from simulation and lifecycle data from quality management, the designer has very clear view about the product and its (reliability, behavior, maintenance cases, failure modes, crack and deformation), so optimizing the design and apply innovation in next generations-designs will be easier and absolutely cost-time effective. Indeed, this system needs high level of cooperation between managers and designers to achieve the best results.

5. Case Study

As a model for case study, we used a design for turbine-Blade model. The blade is a major important component for gas or steam turbines which makes up the turbine section and extracting energy from the high temperature, high pressure gas is produced by the combustor.

The model of blade completely [9] effected on turbine efficiency and productivity. Blade design, test and manufacture are accurate and complicated stage because this part will work under structural stresses, thermal stresses and dynamical stresses.

The margin of error or failure has to be very small, that’s why we used FEA-QLM process to control the blade’s design and optimize the model of course based on work conditions and uses [10, 11].

The case is really huge and has many details that is why we take in consideration the parametric design of the blade and structural analysis using FEA. Fig. 5 shows blade’s geometry and the basic parameters of its design.

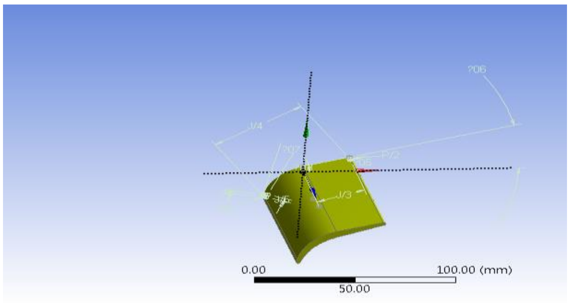


Fig. 5. *Blade geometry and design parameters using ANSYS-academic software*

The model has many design parameters like chord, span length, stagger, head angel (alpha 1, alpha 2) like we see in Fig. 6 which shows also the reaction of the blade cross section and flow pattern in operating conditions [12].

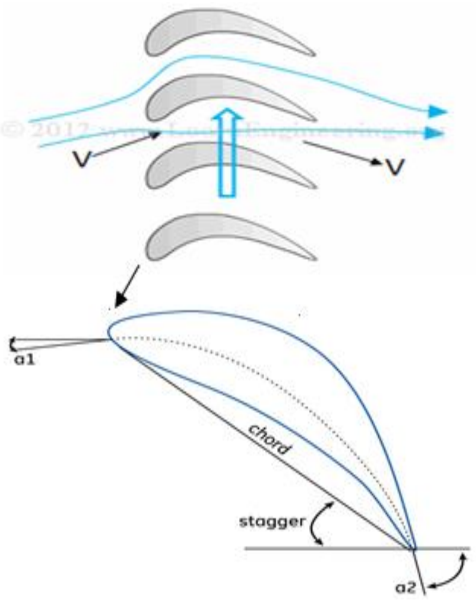


Fig. 6. *Design’s parameters of turbine’s blade and a typical reaction turbine rotor cross section and flow pattern- the figure from: (http://www.learnengineering.org/2013/02/ working-of-steam-turbine.html)*

5.1. Turbine’s Blade-Analyzing

To apply FEA-QLM system on Blade’s model, all mentioned steps above should be followed step by step.

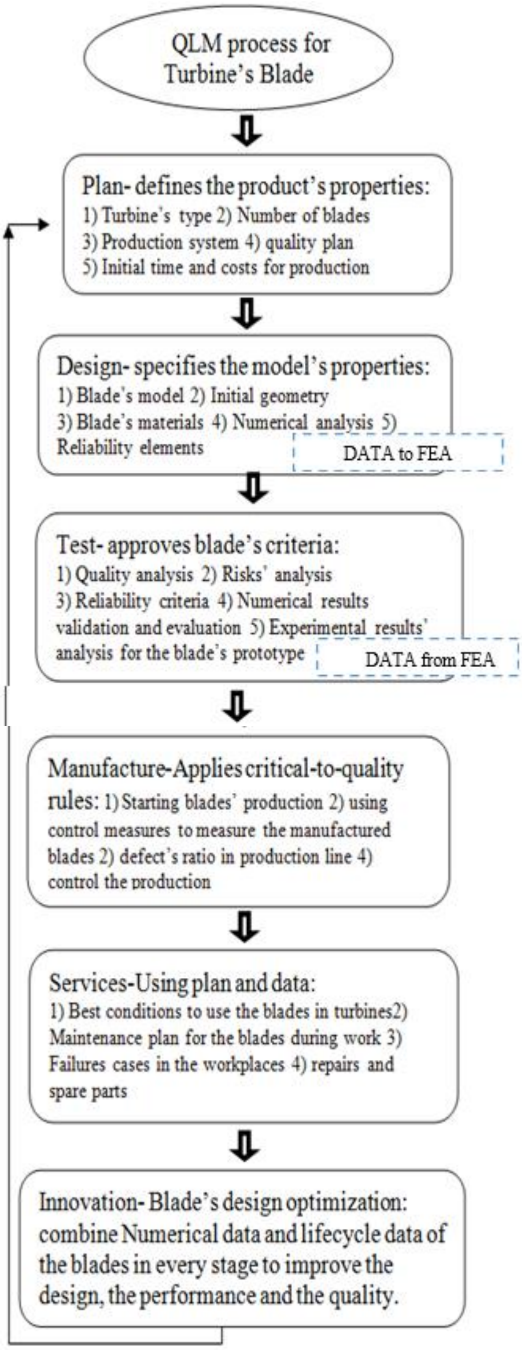


Fig. 7. QLM-Blade process

5.2. Results and Discussion

Fig. 7 show FEM-QLM integrated system to analyze and improve the design of our Turbine's Blade and the materials and operating conditions have written based on industrial case applied in factory [11].

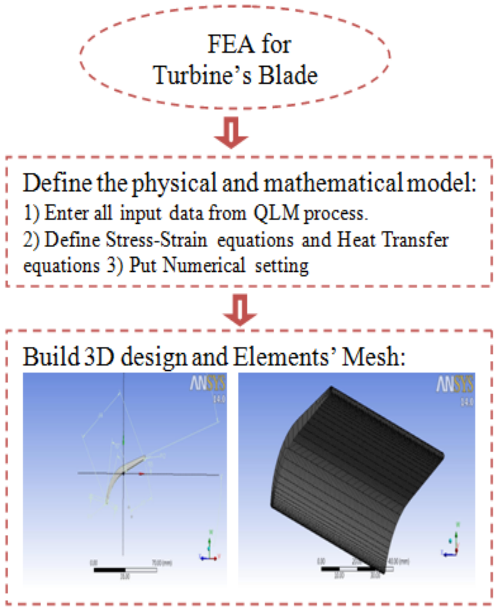


Fig. 8. *First step in FEA process- Create the CAD model and the elements' network (Mesh)*

The internal FEA process will be displayed separately to show the simulation steps which have been made on ANSYS-Structural code and how we can adapt the Numerical solution.

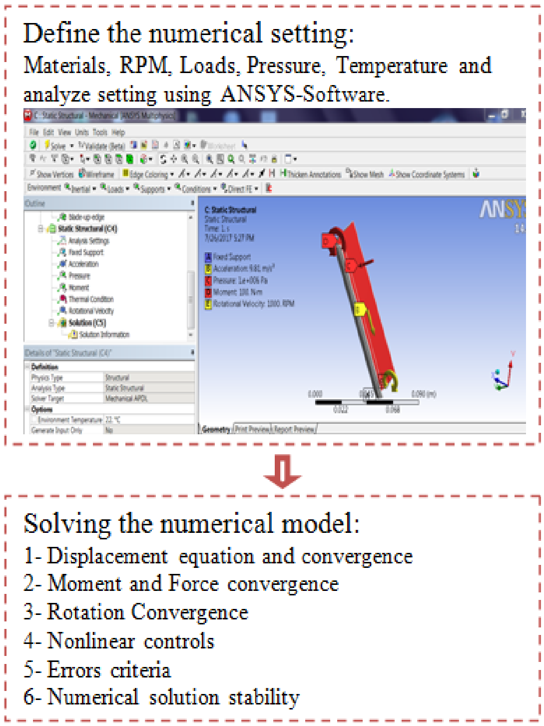


Fig. 9. *Second step in FEA-Define Numerical setting and Boundary conditions in ANSYS-Structural environment*

Fig. 8 shows the first step in the process, which contains creating the CAD model and input data from QLM process.

The second step will define the Numerical setting for our model as we see in Fig. 9, indeed this step is very sensitive and important because it will lead the solution and control the accuracy of the results, so should be done very carefully.

ANSYS-Structural code has a flexible environment, which allows the designer to adapt the setting and choose the loads affecting on the blade. For turbine blade model two calculations should be done, one is the structural analysis, which is the case study for this paper and the other will be the CFD (Computational Fluid Dynamic) [13, 14] flow analysis, which will be the future work.

The Third step is submitting the numerical solution for the model, according to that a personal computer station I5-4GB RAM has been used and the solution was repeated 2 times for assuring the convergence, however the convergence limit was adapted at 0.0001.

Under three different loading cases, deformation, strain and stresses have been resulted; so, the designer can estimate the behavior of the blade under each operating condition. The loading cases are shown in Table 1.

Fig. 10 displays the total deformation in the blade's body under the loading case No. 1.

***Table. 1** Loading cases which applied on the blade in Numerical solution*

Loading case Number	RPM for Blade	Operating Temperature	Loading force on Blade
No. 1	2500	60 °C	35 N
No. 2	2800	70 °C	50 N
No. 3	3000	75 °C	60 N

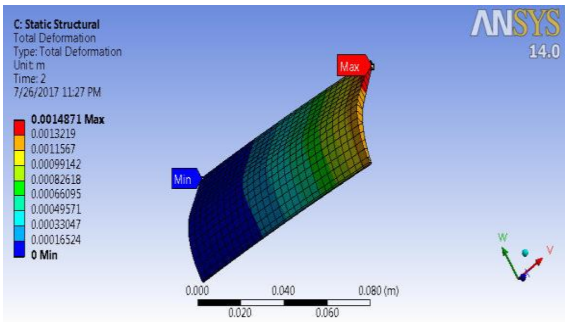


***Fig. 10.** Total deformation on the Blade under Loading case No. 1*

The strain distribution on the blade is an important parameter to estimate, so we can identify the areas with high strain (red color) and areas with low strain (blue color) like as Fig. 11 shows.

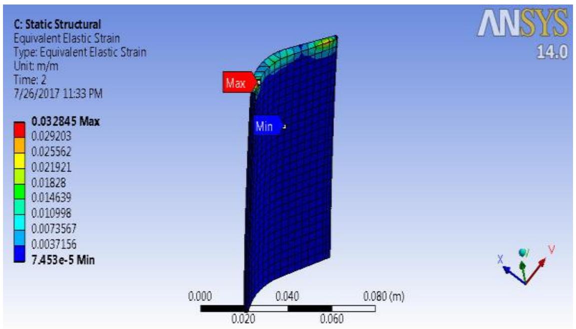


***Fig. 11.** Strain contour on the blade's body under Loading case No. 1*

To analyze the structural behavior of the model, we have to estimate the stress created on the blade's body, especially the maximum shear stress, maximum normal stress and equivalent stress. In Fig. 12 the max shear stress can be noticed and Fig. 13 shows the maximum principal stress distribution on the body displayed (high stress values in red color and low ones in blue color). To summarize the results for loading Cases, Table. 2 displays the changes in results because of changing the loading case. Fourth step in FEA process consists in applying a parametric study [15] on the model in order to optimize the design of the blade in order to find the most effective and efficient one, and send this information to QLM process which can (depending on this data) identify the best design to be made as a prototype in the laboratory to perform an exponential test.

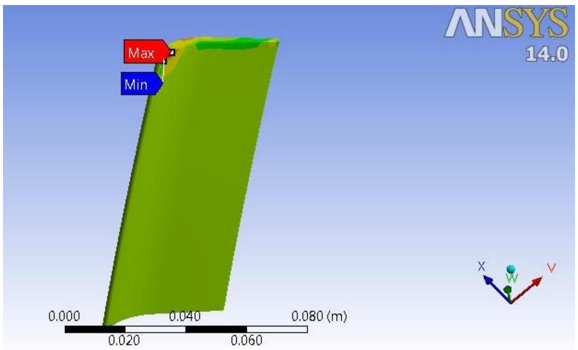


***Fig. 12.** Max shear stress under Loading case No. 1*

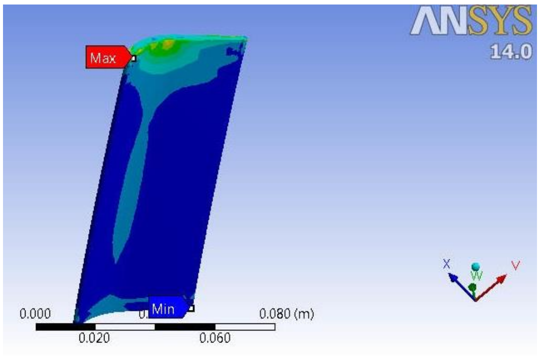


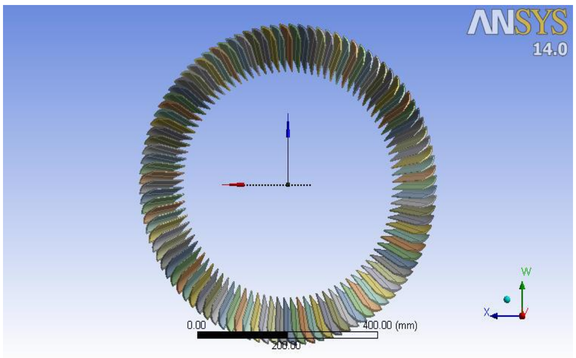
Fig. 13. *Max principal stress distribution on the blade under the loading case No. 1*

Table. 2. *The main results of FEA under three loading cases for blade's model*

Loading case number	Max total deformation, mm	Max shear stress, MPa	Max principal stress, MPa
No. 1	0.0014	63.2	86.5
No. 2	0.00152	67.3	86.7
No. 3	0.0017	70.04	90.6

The designer engineer can use the ANSYS code to perform this parametric study by creating many design points and calculate the max deformation, strain and stress for every point directly. This function is very efficient to analyze all possible loading cases for the model and can provide fast and direct results for parameters which are chosen by the designer.

The last step for FEA process will be results validation by comparing our result with experimental data, however this step will be available after assembling the blade in a complete turbine model as shown in Fig. 14 and performing the CFD flow simulation. This step will be the subject of future work to develop the FEA-QLM integrated process and combine the CFD simulation in it.



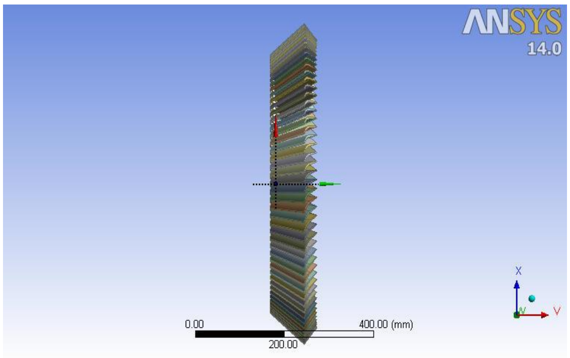


Fig. 14. *assembling the blades in one combination mechanism to perform the CFD calculation as a future work*

6. Conclusion

- FEA helps the designer and manufacture to analyze every Quality parameter during the life-cycle management.
- FEA gives the designer the possibility to test the part under many loading cases and estimating the resulted stresses, strains, deformations, fractions.
- Simulation engineering can show the relationships between all designed parameters (RPM, forces, materials, temperature) in direct and non-direct ways.
- We can reduce the time and costs to achieve the best possible design for our industrial part by doing the design optimization step during the FEA process.
- Results validation is very important step to assure the Numerical results and it will be the subject for future work by completing the CFD simulation and estimate error's sources.
- The QLM-FEA integrated system gives the designer and the manufacturer ability to control every step of part's production, during designing, manufacturing, managing and maintaining levels.

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