Applying Finite Element Method (FEM) for Solving a Self Cleaning Filtering Battery Module Prototype – Case Study

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Abstract: - Nowadays, the importance of the self-cleaning filtering battery is obvious. The system has to answer both to the requirements of industrial users as well as private users. A lot of work was done to improve the existing solutions with a new model which accomplish the needs of the small users. The work was focused on this sector with the view of designing a module with a simply geometry.
The virtual static check which was realized by using the finite element method, proved that the prototype of the module can support 5 bar pressure without problems. The maximum deformation was around 1,4 mm and was noticed on the bottom place. The repeating of the verification with the use of finite element method, for the cylindrical body a confirmed that this new geometry supported very well the pressure effect. The next year will mark the startup for its production.

Key-Words: - filtering battery, finite element method, modular structure

1 Introduction

The study that is presented in the following was conducted in order to solve the problem of a part included in a hydraulic system – a self cleaning filtering battery prototype.

Nowadays, the importance of the self-cleaning filtering battery is obvious. The system has to answer both to the requirements of industrial users as well as private users. The costs of the battery, the easiness of the usage, the maintenance, the delivery reliability are some of the features that determine the buying decision. A lot of work was done to improve the existing solutions with a new model which accomplish the needs of the small users.

It was remarked that analyzing the initial hydraulic diagram, one can select a sector that can be multiplied in order to create a self-cleaning filtering batteries. This sector contains the following components: a self-cleaning filter, a back-flush valve, an air-flushing valve, pipes and fitting as connection elements. It is presented in figure 1.

The work was focused on this sector with the view of designing a module with a simply geometry which is able to incorporate the back-flushing valve, the filter and all the associate pipelines. Simultaneous these modules have to be easy connected for materializing the filtering batteries with two, three or four filters.

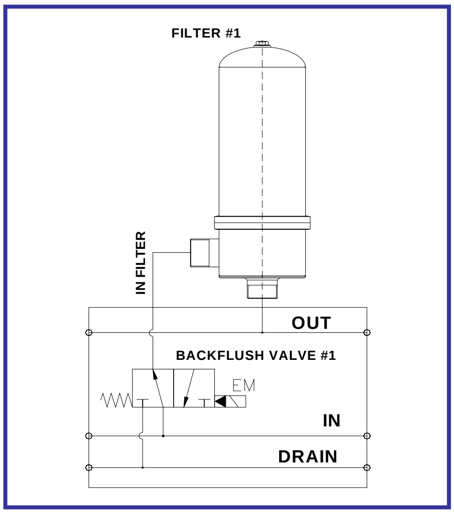

Figure 1: The modular element

2 Theoretical aspects regarding the FEM

A canonical use of FEM is simulation of physical systems. This has to be done by using models, and so the methodology is often called *model-based simulation*. The process is illustrated in Figure 2. The centerpiece is the physical system which is required to be modeled. Accordingly, this configuration is called the Physical FEM. The processes of idealization and discretization are carried out concurrently to produce the discrete model. The solution step is handled by an equation solver often customized to FEM, which delivers a discrete solution (or solutions)[1].

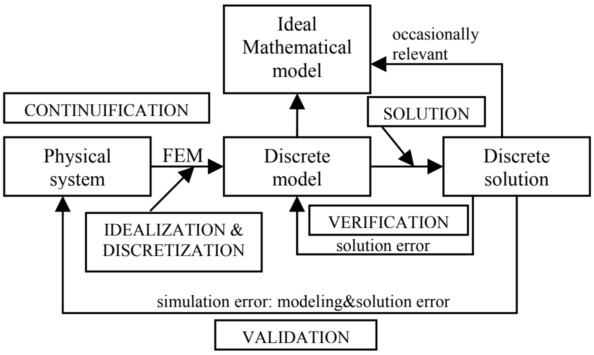

Figure 2: The Physical FEM system

The physical system (top) is the source of the simulation process. The ideal mathematical model (should one go to the trouble of constructing it) is inessential. The figure shows also an ideal mathematical model. This may be presented as a continuum limit or "continuification" of the discrete model. For some physical systems, notably those well modeled by continuum fields, this step is useful. For others, such as complex engineering systems (flying aircraft) it makes no sense. Physical FEM discretizations may be constructed and adjusted without reference to mathematical models, simply from experimental measurements [13],[19].

The concept of error arises in the Physical FEM in two ways. These are known as verification and validation, respectively. Verification is done by replacing the discrete solution into the discrete model to get the solution error. This error is not generally important. Substitution in the ideal mathematical model in principle provides the discretization error. This step is rarely useful in complex engineering systems, however, because there is no reason to expect that the continuum model exists, and even if it does, that it is more physically relevant than the discrete model [5].

Validation tries to compare the discrete solution against observation by computing the simulation error, which combines modeling and solution errors. As the latter is typically unimportant, the simulation error in practice can be identified with the modeling error. One way to adjust the discrete model so that it represents the physics better is called model updating [6],[7] .

The discrete model is given free parameters. These are determined by comparing the discrete solution against experiments, as illustrated in Figure 3. In as much as the minimization conditions are generally nonlinear (even if the model is linear) the updating process is inherently iterative.

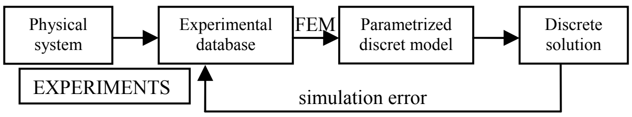

Figure 3: Model updating process in the Physical FEM.

The physical interpretation focuses on the flowchart of figure 2. This interpretation has been shaped by the discovery and extensive use of the method in the field of structural mechanics. The historical connection is reflected in the use of structural terms such as "stiffness matrix", "force vector" and "degrees of freedom," a terminology that carries over to non-structural applications [9].

The basic concept in the physical interpretation is the breakdown of a complex mechanical system into simpler, disjoint components called finite elements, or simply elements. The mechanical response of an element is characterized in terms of a finite number of degrees of freedom. These degrees of freedoms are represented as the values of the unknown functions as a set of node points. The element response is defined by algebraic equations constructed from mathematical or experimental arguments. The response of the original system is considered to be approximated by that of the discrete model constructed by connecting or assembling the collection of all elements [14],[18].

The breakdown-assembly concept occurs naturally when an engineer considers many artificial and natural systems. For example, it is easy and natural to visualize an engine, bridge, aircraft or skeleton as being fabricated from simpler parts.

If the behavior of a system is too complex, the recipe is to divide it into more manageable subsystems. If these subsystems are still too complex the subdivision process is continued until the behavior of each subsystem is simple enough to fit a mathematical model that represents well the knowledge level the analyst is interested in. In the finite element method such “primitive pieces” are called elements. The behavior of the total system is that of the individual elements plus their interaction. A key factor in the initial acceptance of the FEM was that the element interaction can be physically interpreted and understood in terms that were eminently familiar to structural engineers [12].

3 Problem Formulation – Cube Model

The size of the module was defined in correlation with the size of the filter. Thereby, for 3m/sec. water speed, it was chosen an IN/OUT tube section of 100 cm^2. This section made possible the coupling of till four self-cleaning filters. The batteries can deliver from 700 l/min (42 m^3/hour) till 1400 l/min (84 m^3/hour). The first prototype was realized by using the rapid prototyping technology (SLS method). The part that was analyzed is the next.

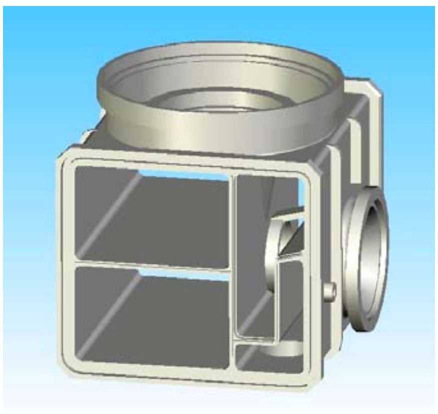

Figure 4: The analyzed part

When is checked an existing product, the geometry is already determined. The goal is to find the optimal form, to check the performance of the product under different working conditions and investigate the possibility of improving the performance or saving material for this occurrence.

A model is usually subjected to dissimilar service environments and operational conditions during its life. It is consequently imperative to consider all potential scenarios of loads and boundary conditions and try different material properties in the analysis of a model [17].

A design scenario is defined by the following factors: model dimensions, study type and related options to define analysis intent, material properties, loads and boundary conditions [2].

The SolidWorks designing software was used because of the fact that it has as basis for the parts behavior analysis the CosmosWork software. The study properties are revealed in the subsequent table.

Mesh Type	Solid mesh
Mesher Used:	Standard
Automatic Transition:	Off
Include Mesh Controls:	Off
Smooth Surface:	On
Jacobian Check:	4 Points
Element Size:	6.1503 mm
Tolerance:	0.30752 mm
Quality:	High
Number of elements:	88509
Number of nodes:	163500

Table 1: Study properties for cubic model

The tests that were done are for stress, strain, displacement and design check. The results which were obtained are the following.

- stress results

Type	Min	Location	Max	Location
VON: von Mises stress	0.00568 021 N/m^2 Node: 84179	(-0.01 m, 0.01 m, 0.169 446 m)	9.81892e +007 N/m^2 Node: 43985	(0.13647 m, 0.155576 m, 0.1815 m)

Table 2: Stress test for cubic module

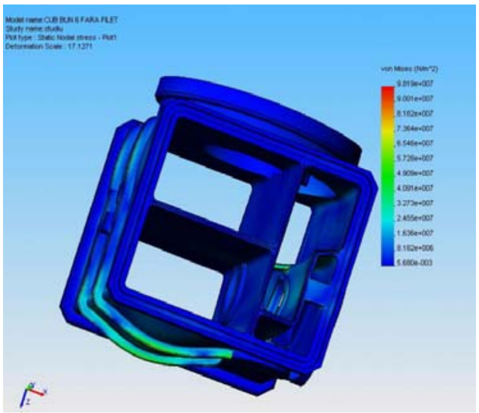

Figure 5: Graphical representation of stress result of the cubic module

- strain results

Type	Min	Location	Max	Location
ESTRN	5.8338e-007 Element: 87579	(0.205 m, 0.236275 m, 0.159991 m)	0.00719342 Element: 63976	(0.136666 m, 0.155174 m, 0.181638 m)

Table 3: Strain test

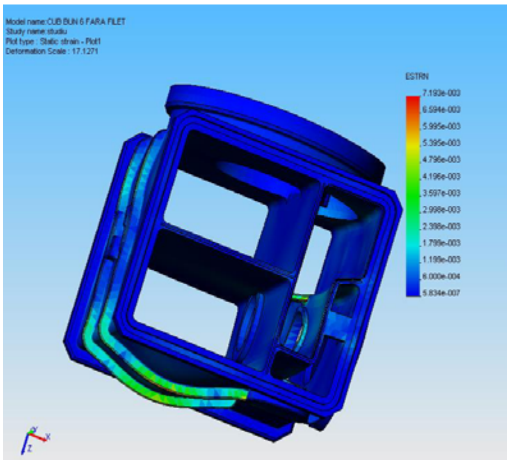

Figure 6: Graphical representation of strain result

- displacement results

Type	Min	Location	Max	Location
URES: Resultant displ.	1e-030 mm Node: 9798	(0.199 m, 0.012 m, 0.005 m)	1.38786 mm Node: 126031	(0.0686121 m, 0.113692 m, 0.1715 m)

Table 4: Displacement results for cubic module

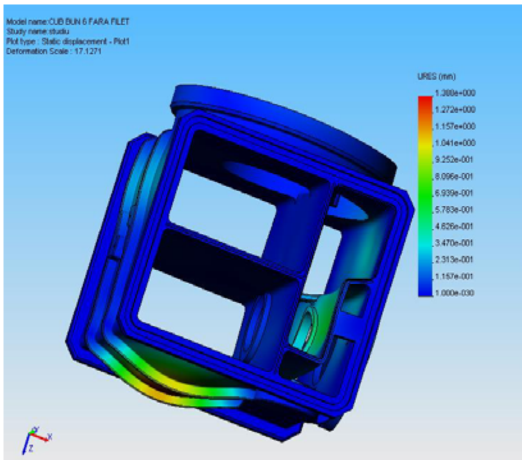

Figure 7: Graphical representation of displacement result for cubic module

- design check results

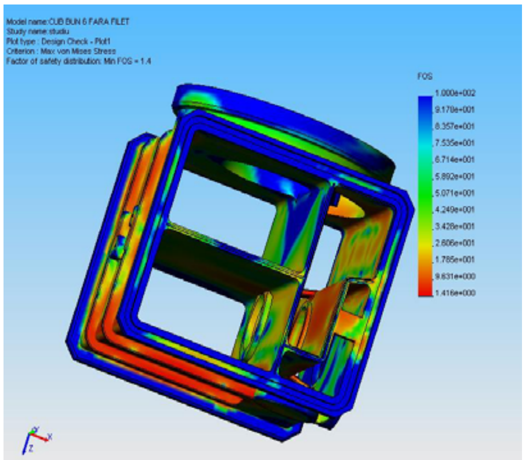

Figure 8: Graphical representation of design check result

The virtual static check which was realized by using the finite element method, proved that the prototype of the module can support 5 bar pressure without problems. The maximum deformation was around 1,4 mm and was noticed on the bottom place. Another important deformation was showed at the valve cavity. Here the deformation was about 0,5 mm and induced the blockage of the mobile part (the piston). The valve did not work safety, sometime functioned and sometime was blocked.

Due to the weak results it was necessary to change the design of the module and flushing valve in order to solve the problems previously presented. This new cylindrical design keeps integral the new concept exposed in the patent proposal.

3 Problem Solution – Cylindrical Module

It was made a new verification, with the finite element method, for the cylindrical body and the result confirmed that these new geometry supported very well the pressure effect. The new design of the module is illustrated in figure 9.

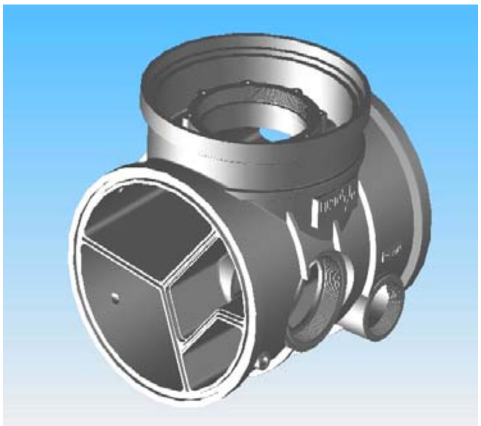

Figure 9: The new module

For this application it was make use of Nylon 6/10 with the following properties.

Property Name	Value
Elastic modulus	8.3e+009 N/m^2
Poisson's ratio	0.28
Shear modulus	3.2e+009 N/m^2
Thermal expansion coefficient	3e-005 /Kelvin
Mass density	1400 kg/m^3
Thermal conductivity	0.53 W/(m.K)
Specific heat	1500 J/(kg.K)
Yield strength	1.3904e+008 N/m^2
Tensile strength	1.4256e+008 N/m^2
Compressive strength	0 N/m^2

Table 5: The unit system properties

The study properties are exposed in the succeeding table.

Mesh Type	Solid mesh
Mesher Used:	Standard
Automatic Transition:	Off
Include Mesh Controls:	Off
Smooth Surface:	On
Jacobian Check:	4 Points
Element Size:	6.1848 mm
Tolerance:	0.30924 mm
Quality:	High
Number of elements:	71173
Number of nodes:	130405

Table 6: Study properties for cylindrical model

The material is said to be isotropic if its properties do not vary with direction. Isotropic materials therefore have identical elastic modulus, Poisson's ratio, coefficient of thermal expansion, thermal conductivity, etc. in all direction .

The term *isothermal* is some times used to denote materials with no preferred directions for coefficients of thermal expansion. In order to define the isotropic elastic properties, you can input a combination of any two of the following properties: elastic modulus Ex, Poisson's ratio ν_{xy}, and shear modulus, G_{xy}. The third property, if not specified, is internally computed by the program using the relation:

(1) $$E = 2G(1+\nu)$$

The stiffness matrix for an isotropic material contains only two independent coefficients. For problems with in-plane loading, finite element analysis is frequently performed using plane elements for which two dimensional stress-strain relations are applied [10],[11]. The deformation states in two dimensions can be either plane stress or plane strain, and for either one of these states to prevail, the plane under consideration (normally, the x-y plane) must be a plane of elastic symmetry [3]. The most general form of the isotropic stress-strain relations including thermal effects is shown below:

(2) $$\begin{Bmatrix}\sigma_x\\ \sigma_y\\ \sigma_z\\ \sigma_{xy}\\ \sigma yz\\ \sigma_{zx}\end{Bmatrix} = \begin{bmatrix} 1-\nu & \nu & \nu & 0 & 0 & 0\\ \nu & 1-\nu & \nu & 0 & 0 & 0\\ \nu & \nu & 1-\nu & 0 & 0 & 0\\ 0 & 0 & 0 & \frac{1-2\nu}{2} & 0 & 0\\ 0 & 0 & 0 & 0 & \frac{1-2\nu}{2} & 0\\ 0 & 0 & 0 & 0 & 0 & \frac{1-2\nu}{2}\end{bmatrix}\left(\begin{Bmatrix}\varepsilon_x\\ \varepsilon_y\\ \varepsilon_z\\ \gamma_{xy}\\ \gamma_{yz}\\ \gamma_{zx}\end{Bmatrix} - (T-T_0)\begin{Bmatrix}\alpha\\ \alpha\\ \alpha\\ 0\\ 0\\ 0\end{Bmatrix}\right)$$

The results of the new testing are presented in the following. The same as in the case of the cubic, the tests were done for stress, strain, displacement and design check.

- stress results

Type	Min	Location	Max	Location
VON: von Mises stress	48094.1 N/m^2 Node: 91345	(0.0583611 m, 0.24095 m 0.0685126 m)	3.20446e+007 N/m^2 Node: 110711	(0.0854883 m, 0.132782 m, 0.0261043 m)

Table 7: Stress test for cylindrical module

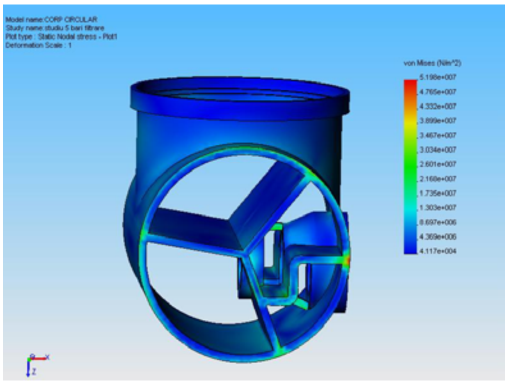

Figure 10: Graphical representation of stress result
for the cylindrical module

- strain results

Type	Min	Location	Max	Location
ESTRN	2.09663e-006 El: 53244	(-0.0909795 m, 0.122 m, -0.0939222 m)	0.00240127 Element: 56500	(0.0867584 m, 0.1243 m, -0.0241752 m)

Table 8: Strain test for the cylindrical module

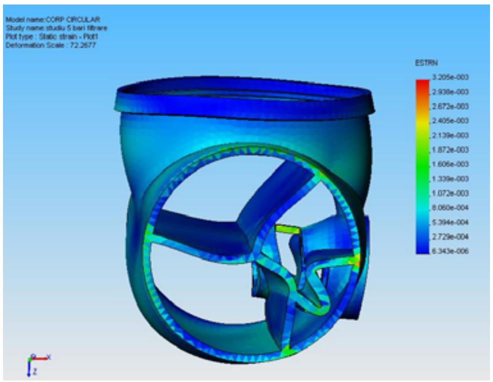

Figure 11: Graphical representation of strain result
for cylindrical module

- displacement results

Type	Min	Location	Max	Location
URES Resultant isplacement	0 m Node: 268	(0 m, 0.231702 m, 0.102888	0.000222877 m Node: 73405	(0.0461853 m, 0.0721231 m, 0.0205999

Table 9: Displacement results for cylindrical module

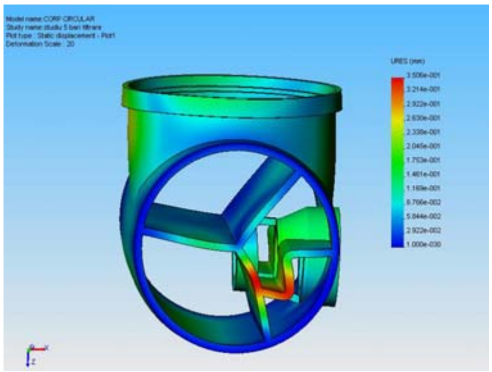

Figure 12: Graphical representation of displacement result for cylindrical module

- design check results

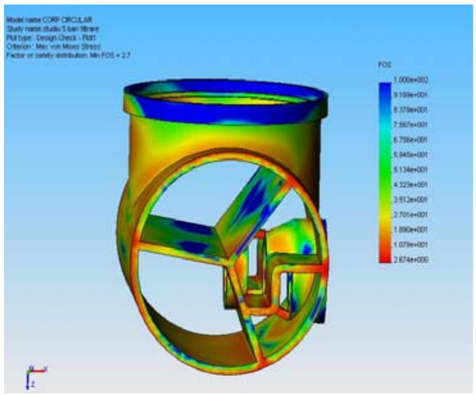

Figure 13: Graphical representation of design check result for the cylindrical module

The repeating of the verification with the use of finite element method, for the cylindrical body a confirmed that this new geometry supported very well the pressure effect.

In this case, the maximum deformation did not exceeds 0,23 mm (at 5 bar) and 0,46 mm (at 10 bar) on the place showed with red color on the figure 5. For comparison, the maximum deformation of the cubical module, at the 5 bar was 1,4 mm.

4 Conclusion

Applying the finite element method were analyzed two versions of a module from a hydraulic system. It was proved that the first design of the module, the cubic version, did not accomplish the maximum deformation requirement.

The new version is recommended to be implemented. Future work will be done for the development of self cleaning batteries filters. The modular idea is a new one in their construction, generating decrease in cost, production time and simplifying the maintenance aspects.

The patent was registered and the prototype can be seen in fairs. The next year will mark the startup for its production.

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