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NUMERICAL STATIC ANALYSES OF PANELAIR FILTER PROTOTYPE

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Abstract. *The Laboratory for air quality control at the Faculty of Occupational Safety in Niš in cooperation with several companies designed and produced the prototypes of industrial panel dust filters, as well as the prototypes of charcoal cartridge filters. In order to obtain comprehensive and valid research results, the authors carried out a number of field tests as well as numerical simulations and analyses of operating parameters and characteristics of several air purifier prototypes on original experimental setup. The aim of this paper is to present simulation results of static (stress and strain, including thermal effect) analyses of industrial air filter prototype. Simulation and visualization of results was done by means of SW SimulationXpress and SW simulation design study modules from Solid Works software package.*

Key words: *air filter prototype, numerical simulation, static analysis*

1. INTRODUCTION

Nowadays, the answer to questions like whether a part will break or deform, or whether to use more or less material without affecting performance, can be obtained by different means, which can be divided in two main approaches. The first one can be described as numerous field tests of prototypes with evaluation results, which implies modification of part design processes until a satisfactory solution is reached.

On the other hand, simulation can help accomplish the tasks such as optimizing designs by simulation concepts before making final products and reducing costs and time by testing models with a computer. This is very important if one is to maintain cheaper and more efficient production and to market products faster than the competition, and thus gain higher profits.

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Stress or static analysis calculates the displacements, strain, and stresses of a part based on material, fixtures, and loads. A different material fails when the different stress levels reach a certain level. SW SimulationXpress module and SW Simulation design study, used in this paper, utilize linear static analysis, based on the Finite Element Method, to calculate stresses. Linear static analysis makes several assumptions to calculate stresses in a part. Those assumptions are Linearity assumption (the induced response is directly proportional to the applied loads); Elasticity assumption (the part returns to its original shape if the loads are removed and it has no permanent deformation); and Static assumption (loads are applied slowly and gradually until they reach their full magnitudes).

The Finite Element Method (FEM) is a reliable numerical technique for analyzing engineering designs replacing a complex problem with many simple problems and dividing the model into many small pieces of simple shapes (elements).

Solid Works SimulationXpress is suitable for stress analysis of simple parts (sub-assemblies), and we used it to simulate the effects of force or pressure.

Static analysis computes the effects of static loading on a model. It can display stresses, strains, displacement, and the factor of safety at each segment of a model. In Simulation, one has to specify the location and magnitude of each load, as well as to specify where and how the model is supported. Identifying where stresses are the highest/lowest quickly shows the designer where a model can be improved by adding support or by removing excess material. From the results, we can choose the optimal configuration with required factor of safety, load conditions, or stress tolerance.

In addition to software simulation, we conducted field tests on the original experimental setup. Experimental apparatuses were constructed as a complex system of ventilation channels; air conditioning module; filter modules for mechanical and chemical air purifiers; data acquisition; modules for simulation of mechanical and chemical pollutants; velocity; temperature; humidity and differential pressure transmitters; fan unit with frequent regulation, etc. Behaviour of elements which share common points called nodes is well-known under all possible support and load scenarios. The motion of each node is fully described by translations in the X, Y, and Z directions, called degrees of freedom (DOFs). Analysis using FEM is called Finite Element Analysis (FEA). The equations, formulated by SimulationXpress, describe behaviour of each element with regard to other elements, relating displacements to known material properties, fixtures, and loads. In addition, SimulationXpress organizes the equations into a large set of simultaneous algebraic equations, and the solver calculates the displacements in the x, y, and z directions at each node, and then the stresses and strains in various directions.

2. MODULE OF INDUSTRIAL AIR FILTER PROTOTYPE

Module of industrial air filter prototype represents a compact in-and-out line segment of a laboratory probe line with a square cross-section. It consists of a straight channel parallelepiped shape, with 600 [mm] in length, connected to two diffusers with opposite directions. Full length of the purifier module is 1270[mm]. The length of the module is the result of its design, which means allowing for flow and spatial properties of the system, as well as connecting a round cross-section of the channel and square cross-section of the module. Sides of the module and the diffuser are made of PVC plates through mechanical treatment on a vacuum press. The result obtained is adequate compactness and strength, as well as smoothness of the inner walls of the module, important because of small hydraulic drag or occurrence of small force of friction.

Fig. 1 Module of industrial air filter prototype and data acquisition system

Devices for purification of mechanical pollutants, i.e. panel type filters with appropriate standard dimensions, are placed in the purifier module. With appropriate modification it is possible to load filter screens of both nonstandard dimensions and cylindrical shapes. Filters are loaded within flanges of the connective element, in other words, between front and rear module diffusers. With some modification, it is possible to set up joint activity of the rough and absolute filters (one in front of the other) and the adsorber.

3. INDUSTRIAL FILTER PROTOTYPE

The purifier of mechanical pollutants is an industrial panel filter, which was manufactured for experimental purposes by the well-known domestic manufacturer of filter products “Frad” from Aleksinac. It should be mentioned that this kind of filter is not a part of mass production by the manufacturer but is produced according to specification by the authors of this paper in cooperation with a skilled team of the manufacturer. Internal ID numbers of used industrial panel filters are: IPAF-1 and IPAF-2.

Although authentic, the filter has certain properties within the standard, such as dimensions and materials. Dimensions of the filter screen are 600x600 [mm], and the filling is made of filter paper, manufactured by Neenah Gessner, Germany, with the following properties:

- composition of the paper: cellulose > 80%, phenolic resin min. 17%
- flow: >750[l/m^{2}s] (with pressure drop up to 200[Pa])
- paper thickness: 0.6[mm]
- specific weight: 120[gr/m^2]
- ripping of non-stabilised paper: >1[bar]
- ripping of stabilised paper: >2[bar]
- the biggest pore: 75[μm]
- average pore: 55[μm]

Figure 2 shows the filter IPAF-1:

Filter of mechanical pollutants is located at the beginning of the purification module and behind the front diffuser. It is fixed by tightening screws through a flange.

Properties of the filter element of the filter IPAF-1:

- filtrating area A= 6,5[m^2]
- flow at pressure drop of Δp= 200[Pa]: Q=800[l/m^2s]
- nominal fineness of filtration: F= 13,5 – 19[μm]
- ripping point: P= 2,5[bar]

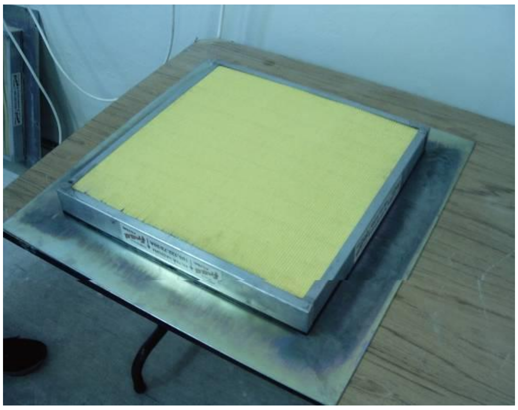

Fig. 2 Filter IPAF-1, view of the front, inlet side

Filter element IPAF-2 is made of polypropylene filter cloth which forms the basis for fine particle filtration and high strength and excellent resistance to most acids and alkalis. The middle filter paper (fine absolute) has the following properties:

- flow at pressure drop of Δp=200[Pa]: Q>100[l/m^2s]
- paper thickness: 0.65[mm]
- specific weight: 140[gr/m^2]
- ripping point: >3[bar]
- the biggest pore: 25[μm]
- average pore: 18[μm]

Properties of the filter element of filter IPAF-2:

- filtrating area: A=6,5[m^2]
- flow at pressure drop of Δp=200[Pa]: Q=110[l/m^2s]
- nominal fineness of filtration: 4 – 6[μm]
- ripping point: P= 3[bar]

Figure 3 shows the filter IPAF-2:

Fig. 3 Filter IPAF-2, view of the rear side reinforced by perforated foil

4. The Results of Simulation - Stress Analysis - the Part of Filter Medium IPAF-2

1. Materials

No.	Part Name	Material	Mass	Volume
1	filter_paper	PP filter cloth	0.38 kg	0.00045m^3

2. Load & Restraint Information

Restraint		
Restraint-1 <filter_paper>	on **4 Face(s)** fixed by glue.	
Load		
Pressure-1 <filter_paper>	Pressure **5e+005 N/m^2** along direction normal to selected face	Sequential Loading

3. Study Property

Mesh Information	
Mesh Type:	Solid mesh
Mesher Used:	Standard
Smooth Surface:	On
Jacobian Check:	4 Points
Element Size:	5.4553 mm
Tolerance:	0.27277 mm
Number of elements:	79073
Number of nodes:	157722
Time to complete mesh(hh;mm;ss)	00:26:45
Solver Information	
Solver Type:	FFEPlus
Option:	Include Thermal Effects
Thermal Option:	Input Temperature
Thermal Option:	Reference Temperature at zero strain: 298 Kelvin

4. Contact

Contact state: Touching faces - Bonded

5. Results

5a. Default Results

Name	Type	Min	Location	Max	Location
Stress1	VON: von Mises stress	0.004864 N/m^2 Node: 62619	(1.89501 mm, 27.0716 mm, 5.55112e-014 mm)	7.68764e+010 N/m^2 Node: 75724	(33.0361 mm, -5.10289 mm, 113.514 mm)
Displacement1	URES: Resultant displacement	0 mm Node: 1	(155.599 mm, -12.8933 mm, 200 mm)	787.607 mm Node: 92204	(66.8518 mm, 15.6942 mm, 100 mm)
Strain1	ESTRN: Equivalent strain	3.33214e-007 Element: 17912	(1.09373 mm, 13.8347 mm, 54.054 mm)	173.14 Element: 67422	(33.0361 mm, -5.10289 mm, 113.514 mm)

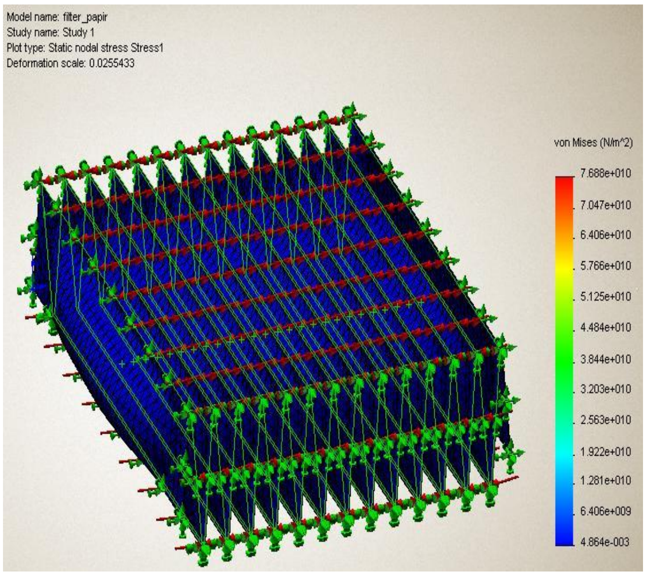

Fig. 4 Filter_paper-Study 1-Stress-Stress1

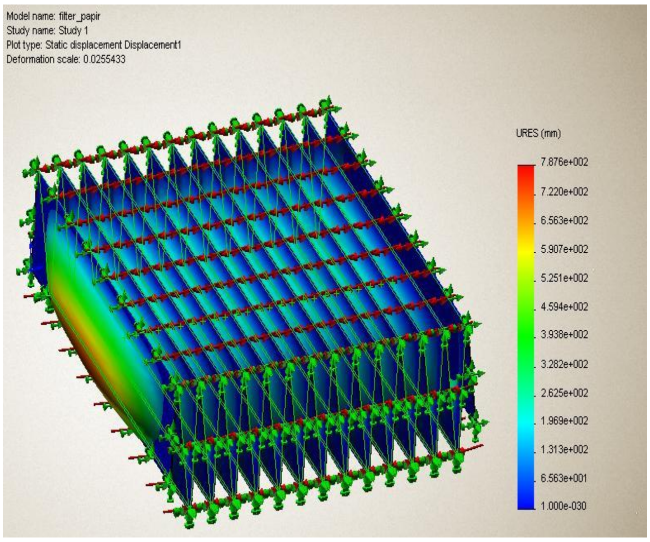

Fig. 5 Filter_paper-Study 1-Displacement-Displacement1

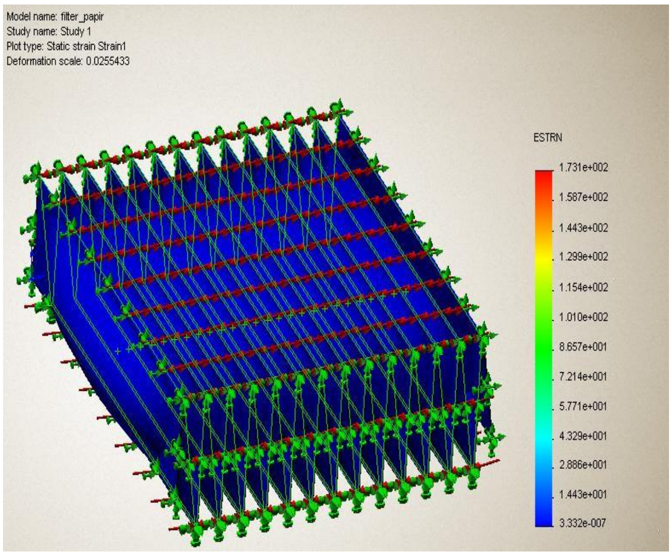

Fig. 6 Filter_paper-Study 1-Strain-Strain1

6. Appendix

Material name: PP filter cloth

Material Model Type: Linear Elastic Isotropic

Property Name	Value	Units	Value Type
Elastic modulus	8.96e+008	N/m^2	Constant
Poisson's ratio	0.4103	NA	Constant
Shear modulus	3.158e+008	N/m^2	Constant
Mass density	890	kg/m^3	Constant
Tensile strength	2.76e+007	N/m^2	Constant
Thermal conductivity	0.147	W/(m.K)	Constant
Specific heat	1881	J/(kg.K)	Constant

5. The Results of Simulation - Stress Analysis of Sub-Assembly - Frame of Filter

1. Materials

No.	Part Name	Material	Mass	Volume
1	ram-1	[SW]Galvanized Steel	1.08503 kg	0.00013787 m^3
2	ram_1-1	[SW]Galvanized Steel	0.234712 kg	2.98236e-005 m^3
3	ram_1-3	[SW]Galvanized Steel	0.234712 kg	2.98236e-005 m^3

2. Load & Restraint Information

Restraint		
Restraint-1 <ram_1-3, ram_1-1>	on **2 Face(s)** fixed.	
Spot Weld Connector-1 <ram_1-3, ram-1>	Spot welds Connectors on **2 Vertex(s), 2 Face(s)**	Sequential Loading
Spot Weld Connector-2 <ram-1, ram_1-1>	Spot welds Connectors on **2 Vertex(s), 2 Face(s)**	Sequential Loading
Spot Weld Connector-3 <ram-1, ram_1-3>	Spot welds Connectors on **2 Vertex(s), 2 Face(s)**	Sequential Loading
Spot Weld Connector-4 <ram-1, ram_1-1>	Spot welds Connectors on **2 Vertex(s), 2 Face(s)**	Sequential Loading
Load		
Pressure-1 <ram-1, ram_1-3, ram_1-1>	on **4 Face(s)** with Pressure **5e+005 N/m^2** along direction normal to selected face	Sequential Loading
Description:		
Gravity-1	Gravity with respect to **Face< 1 >** with gravity acceleration **-10 m/s^2** normal to reference plane	Sequential Loading
Temperature-1 <>	on with temperature **80 Celsius**	

3. Study Property

Mesh Information	
Mesh Type:	Solid mesh
Mesher Used:	Standard
Smooth Surface:	On
Jacobian Check:	4 Points
Element Size:	5.8254 mm
Tolerance:	0.29127 mm
Number of elements:	47134
Number of nodes:	100177
Time to complete mesh(hh;mm;ss)	00:06:18
Solver Information	
Solver Type:	FFEPlus
Option:	Include Thermal Effects
Thermal Option:	Input Temperature
Thermal Option:	Reference Temperature at zero strain: 298 Kelvin

4. Contact

Contact state: Touching faces - Bonded

5. Results

5a. Mesh Quality Plots

5b. Default Results

Name	Type	Min	Location	Max	Location
Stress1	VON: von Mises stress	6928.25 N/m^2 Node: 90384	(-30.5575 mm, 387.506 mm, -40.4313 mm)	2.61127e+009 N/m^2 Node: 74313	(-196.819 mm, 338.94 mm, 3.48038 mm)
Displacement1	URES: Resultant displacement	0 mm Node: 78432	(176.319 mm, 28.2424 mm, -41.4313 mm)	1.96031 mm Node: 74901	(-182.644 mm, 215.006 mm, 4.30526 mm)
Strain1	ESTRN: Equivalent strain	2.96333e-008 Element: 43575	(-34.1491 mm, 389.289 mm, -41.1813 mm)	0.00836945 Element: 21121	(-182.936 mm, 27.6334 mm, 3.81939 mm)

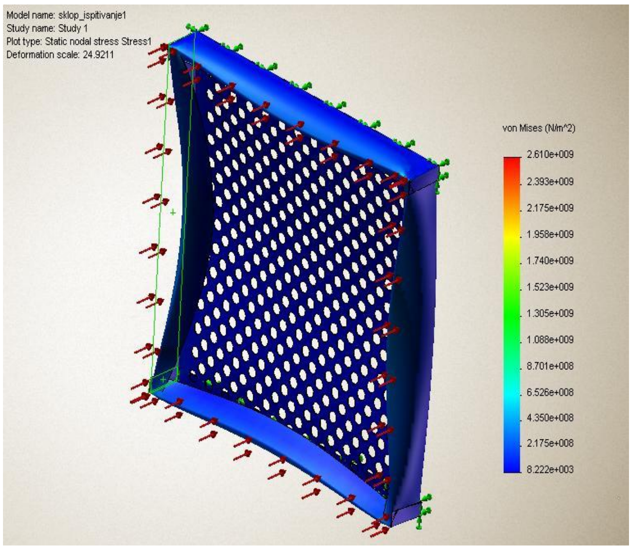

Fig. 6 Results of stress simulation of sub-assembly

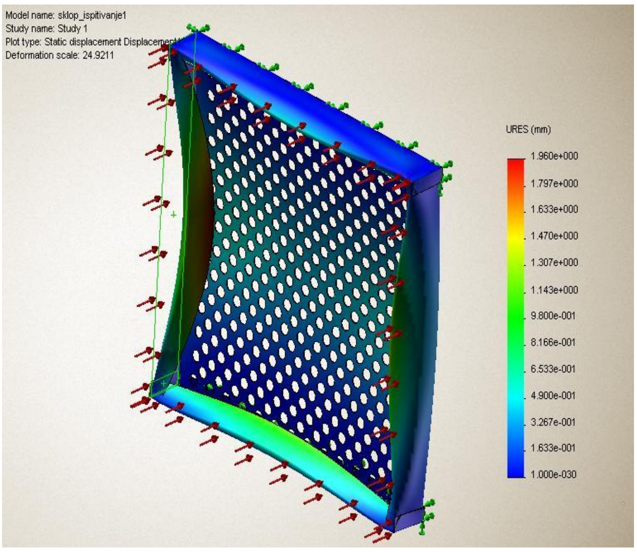

Fig. 7 Results of strain simulation of sub-assembly

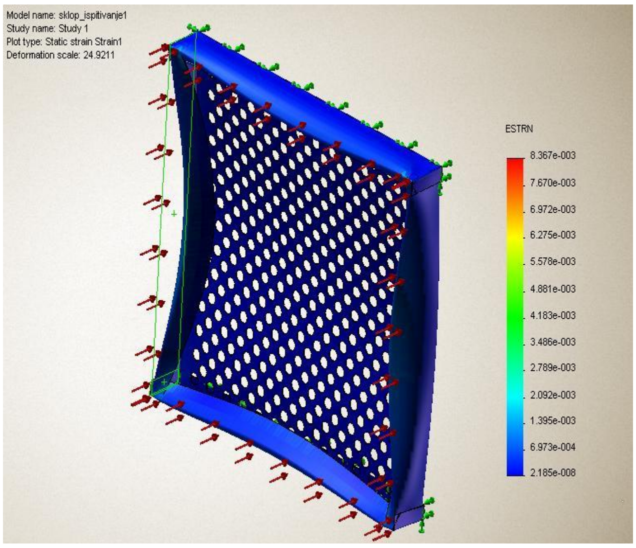

Fig. 8 Results of Displacement simulation of sub-assembly

6. Appendix

Material name: Galvanized Steel
Material Model Type: Linear Elastic Isotropic

Property Name	**Value**	**Units**	**Value Type**
Elastic modulus	2e+011	N/m^2	Constant
Poisson's ratio	0.29	NA	Constant
Mass density	7870	kg/m^3	Constant
Tensile strength	3.569e+008	N/m^2	Constant
Yield strength	2.0394e+008	N/m^2	Constant

6. CONCLUSION

This paper presents a software simulation of connections and elements of sub-assemblies of an industrial prototype panel air filter. Tests related to stress, strains, and deformation of the element's connection were conducted by use of Solid Works software package and modules SW SimulationXpress and SW Simulation design study.

The simulation procedure set parameters for materials and connections between the elements fully meet the criteria for the safety of structures and fracture of panel construction as well as for splitting and perforation of filter filling.

Based on the results of the simulation given in graphs of stress, strain and displacement of investigated elements, which show the quantification of the corresponding size by the colour spectrum, we determined the critical locations.

On the basis of these results and the high safety level, simulations show the possibility of optimization components and sub-assemblies in terms of choice of different materials in order to reduce production costs.

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NUMERIČKA STATIČKA ANALIZA PROTOTIPA PANELNOG FILTERA VAZDUHA

Laboratorija za upravljanje kvalitetom vazduha na Fakultetu zaštite na tadu u Nišu u saradnji sa nekoliko kompanija projektovala je i izradila nekoliko prototipova industrijskih panelnih filtera prašine kao i prototipova kasetnig filtera sa aktivnim ugljem. U cilju dobijanja sveobuhvatnih i validnih rezultata istraživanja autori su sproveli brojna eksperimentalna istraživanja kao i simulacije radnih parametera i karakterisitika nekoliko prototipova prečistača vazduha na originalnoj eksperimentalnoj aparaturi. Suština ovog rada je da prezentuje rezultate numeričkih simulacija opterećenja i statičke analize prototipa industrijskog filtera vazduha. Simulacija i prikaz rezultata rada urađeni su korišćenjem SW modula SimulationXpress i SW Simulation design study u softwerskom paketu Solid Works.

Ključne reči: *prototip filtera vazduha, numerička simulacija, statička analiza*