Supporting Risk-Based Design by Computational Synthesis

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***Abstract*— Risk-based design often starts when the design details are available. Commonly used engineering tools focus on risk assessment for already-detailed designs. This study suggests using automated solutions for early design phases where efficient exploration of design space can lead to solutions that offer better performances with less risk. The paper states the problem, relevant works, and summarizes the steps taken in order to generate solutions for a product complicated to model. A real-world example application is presented.**

Keywords- risk-based design; automation; computational synthesis.

I. INTRODUCTION

Exploration of design space in early design phases is valuable for the project but is expensive. The importance of early design phases is discussed in different literatures [1, 2], yet there are other performance metrics forcing design engineers to assign a certain amount of resources to this phase.

The normal design phase starts with a concept which will be embodied and detailed later on. Since this process is time consuming and given the available resources, this often leads to limited choices for designers [3]. To overcome this limitation, the paper suggests using a detailed model in early design phases where automation provides many choices for the designer. From this palette of possibilities he or she can explore the design space easily and move toward the choices that are closer to the required performances and afford less risk.

A. Risk-based design

Risk is defined as multiplication of probability of failure and its consequence. In order to reduce risk, the probability of failure has to be small. Risk-based design is a promising approach for handling of complex problems [4, 5].

A simple search on google scholar for “risk-based design” finds more than 2800 articles or books. Yet risk based approach is not limited to design. There are literature works for example about risk-based reliability analysis, risk-based evaluation of design criteria, or risk-based decision making processes.

The deterministic approach in design does not fully match the expectations for reliability of products or systems and reveals shortcomings for future development. Limitations of deterministic approaches e.g. the use of safety factors have been discussed for example in [2]. In deterministic approach, safety factors are used to incorporate uncertainty, whereas risk-based design methodology uses probability distributions for risk estimation. The deterministic approach also requires a full scale prototype to be built and tested under working conditions. This, however, is not always a possibility.

In risk-based design process, the probability of failure is used to capture the uncertainties in the course of design process, often providing a more appropriate understanding of the problem. Furthermore, it can be utilized to make the design process more proactive and prepare for unexpected failures [2]. Risk-based design has been actively used in different industries producing standard methods for uncertainty measurement, risk assessment and management [6]. In many practices, however, this has been limited to realization of failure modes determined by designers or engineers. This is often possible only after having a detailed design which makes it costly and inefficient to come back and apply principal changes.

This research moves toward automation of risk-based design process. Integration of risk-based design with automation creates the advantages of both approaches resulting in more efficiency and robustness. And the results are promising, as discussed through the paper. Yet, to achieve its full potential, insight and experience involving the methodology need to be acquired. This has led to the following research question: ”What are the key performances to achieve for design of a specific product?”.

The methodology will be tested on a case by trying to find the best suited solution for this case. The automated part of the methodology uses a generic synthesis tool customised by the authors. The case needs to be translated into a model, which can be used in a computational design synthesis tool.

The remainder of the paper is structured as follows. Section II and III respectively explain the problem and method. Section IV presents an example application, and Section V concludes the paper.

II. PROBLEM STATEMENT

The lengthy process of early design makes the risk-based design a passive process that interferes less little with the early choices, when the designers have the most freedom to choose and change. Therefore, the problem is that treatment of risk during the last design phases causes designers to be reluctant to major changes. In this paper, we explore possible solutions to overcome this issue.

III. THE METHOD

In order to design for risk effectively, one needs to bring the risk next to the other performance indicators considered by designers in early design. This will shorten the design process, and effectively make risk as one of the performance indicators through the design process.

IV. EXAMPLE APPLICATION

The example application presented here is an already existing pressure sensor produced by company STA (pseudo-name, the actual company name is not disclosed). The sensor works at a maximum diesel pressure of 400 MPa and measures the pressure of the injected fuel in an internal combustion engine (see Figure 1).

The sensor has screw-thread on the outside of the housing for screwing it in the common rail. Pressure of the diesel causes the topside to deform together with the attached strain gauges. The strain gauges provide the resulting information instantaneous to the engine's control unit (ECU). Not providing this information will lead to unforeseen and costly failures. Important part of the case will be the potential failure of the walls and the top of the topside of the sensor. When failing, diesel could start leaking and combust within the engine bay. This would result in even higher costs or even worse. For this part, risk-based design will be implemented.

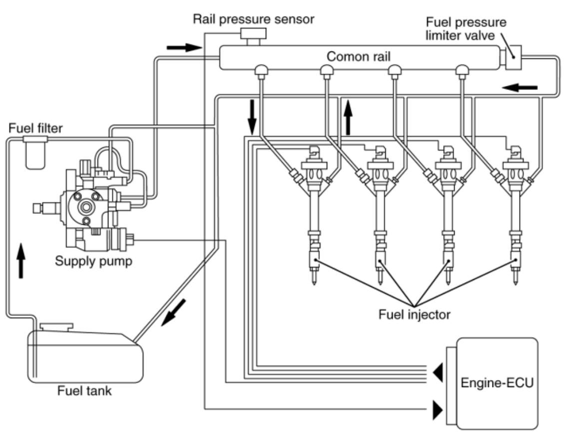

Figure 1. The pressure sensor placed within the system of the engine.

A. Downsized model

After considering the whole sensor, it became clear that all the electronic parts of the sensor could be discarded in the design process, as well as the bottom standardized part of the sensor. These parts where not important in the design process of the sensor, because these parts where similar for all types of sensors. This resulted in neglecting most of the parameters for the bottom of the sensor and leaving only the topside of the sensor (see Figure 2).

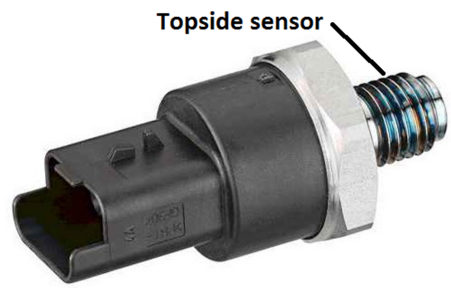

Figure 2. Top (half) of the sensor known as the total sensor

The topside of the sensor holds the key performances, risks and parameters to this design (see Figure 3). The optimal radius of the inside corners are already known at STA and thus will be used due to the fact that including them would overcomplicate the model (0.1 mm inside and 0.4 mm outside). For the same reason pre tensions from tightening the sensor will be excluded.

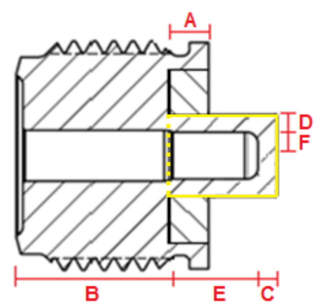

Figure 3. Cross section of the total sensor with the indicated parts (capital letters) for the equation of production cost

B. Model

The variable input parameters, which describe the simplified model (used for the sake of quick calculations), will be divided into dimensions and material parameters (see Table 1). Four ranges of different materials are used: Aluminium, 42CrMo4 steel, 17-4PH stainless steel and PTFE.

Having these parameters, one can calculate the weight, material price, inside volumes and production cost using the synthesis tool. Models have been constructed by the use of equations extracted from the disk and plate theory. For the ease of calculations, round disk/tube situations have been modeled to obtain the stress and deflection equations for the walls and topside. These models have been validated by a precise finite element model implemented in ANSYS software (www.ansys.com) given the accepted tolerance level of 10% (see Figure 4).

TABLE 1. PARAMETERS OF THE DIMENSIONS AND MATERIALS

Dimensions	Parameter	in [mm]
Radius inside (F)	Rinside	[2, 4]
Length walls (E)	Lwalls	[3, 7]
Length bottom sensor (B)	Lbottom	[10, 20]
Length depth gap (A)	Lgap	[0, 3]
Thinkness walls (D)	Twalls	[1, 4]
Thinkness topside (C)	Ttopside	[0.5, 3]
Material parameters	**Name/unit**	
Name	String	
Young's modulus	E [Mpa]	
Poisson ratio	v [-]	
Density	Den [kg/mm³]	
Price	P [€/kg]	
StressMax	σmax [N/mm²]	

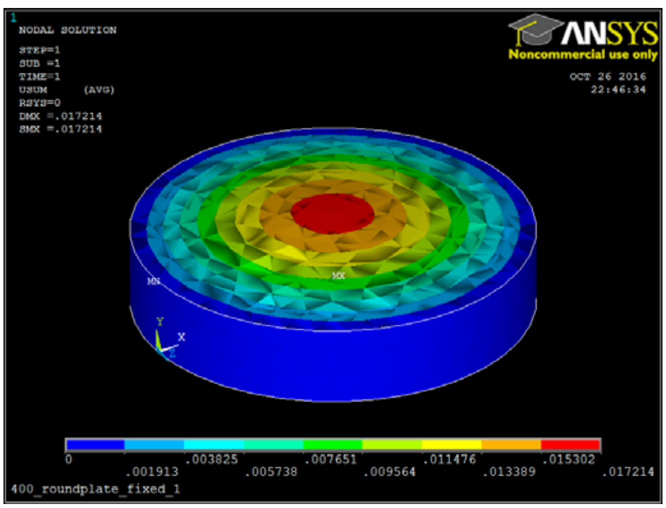

Figure 4. Deflection in the fixed round disk scenario (1,72e-2mm)

To verify the equations and have certain accuracy in the solutions, the equations had to be within a maximum range of 15% of the finite element model. It became clear that the round corners had a positive influence on the deflection on the topside. An adjustment had to be made combining the equation for a fixed round plate with 20% of the equation of a hinged round plate (read topside). All other equations were within their maximum scope.

C. Results

The model was implemented in the computational synthesis tool resulting in a set of possible solutions with their corresponding input parameters and performances. Two example set of solutions are given in Table 2.

TABLE 2. TWO SOLUTIONS OF THE MODEL (WITH THEIR INPUT PARAMETERS AND PERFORMANCES) GIVEN FOR TWO DIFFERENT MATERIALS

Input parameters [mm]	42CrMo4	17-4PH
Rinside	2,44	2,3
Lwalls	5,17	4,43
Lbottom	16,76	12,83
Lgap	0,76	2,75
Twalls	3,98	2,86
Ttopside	2,45	1,08
Performances		
Volume 1 [mm³]	96,7	73,7
Volume 2 [mm³]	409,8	287,3
Productioncost [$]	0,92	0,85
Weight [kg]	0,0102	0,0002
Price [€]	0,00023	0,00078
Deflection [mm]	0,0014	0,0129
Stress topside [N/mm²]	547,76	623,04
Stress walls [N/mm²]	263,29	1215,18

Both PTFE and Aluminium had no possible solution, within the range of input parameters, due to reaching the stress limit for these materials (as expected). To be able to find the most appropriate solutions a trade-off needs to be made between different performances and input parameters.

We observed that the importance of a clear understanding of the key performances is significant. It is important to notice that the approach does not necessarily lead to the optimum solution, yet it helps designers to compare different possible choices and make we-informed choices with regard to different parameters and performances.

The approach, therefore, supports designers to make better trade-offs by for example choosing the more appropriate material, thickness, etc..

V. CONCLUSIONS

Automation of risk based design process and exploration of different solutions in early design phases provide further insights for designers and helps choose more appropriate solutions with regards to risk.

To make well-informed choices and better trade-offs, a good understanding of key performance and key parameters is fundamental. In addition, a model with the right amount of information and detail is necessary. To properly utilize this process, a designer should be able to realize the key parameters and their relationship with the desire performance indicators e.g. risk.

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