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Virtual Product Development on Venturi Pump

Market globalization and increased customer demands are leading providers of low product series to the high cost of development and construction. To overcome noted challenges it is necessary to use process of virtual product development. In that way it is possible, even in early phases of product development, to assess the operational product behaviour. Even the specific customer demands are determined before the actual product design phase. The paper presents an up to date concept of virtual product development with application on assessment of operational behaviour of Venturi pumps.

Keywords: *virtual product development, CFD, optimisation, Venturi pump*

1. Introduction

Application of computer aided design radically changes the auxiliary aids and tools in product development. Significant calculation speed and ability to easily manage and store data led to development and application of algorithmic systems, such is the finite element method. By application of geometric modelling the product models were obtained from which it was possible to make design documentation, perform numerical calculations, to plan production as well as getting the base to manufacture with numerically controlled machine tools and robots.

In this way it is possible to consider concurrently function, geometry and technology as well as their interrelations. Computer aided product modelling integrates noted tasks and enables the formation of computer integrated factory. Process of product modelling enables, beside geometric data, to obtain data about product model which represent a basis for the new approach to product development known as virtual product development.

Given the possibility of information technologies, the computer support is used in all phases of product development. Therefore, the virtual product, i.e. simulation of all product phases in product development process, aided by the computer, can be recognized as a strategic goal.

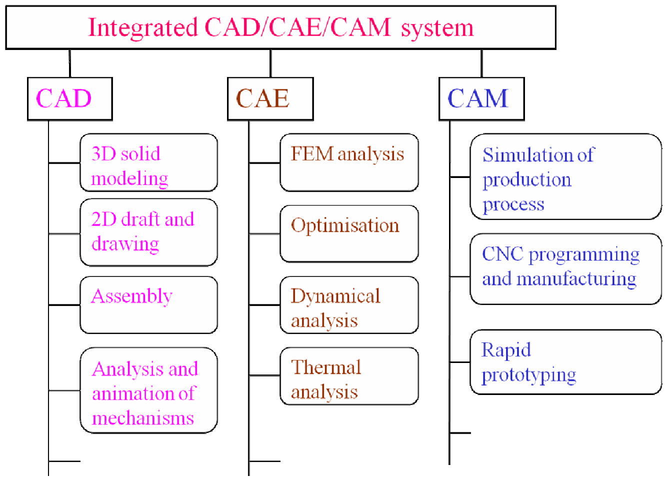

Figure 1. Integrated CAD/CAE/CAM system.

The process of virtual product development includes support for computers in the assessment and evaluation of proposed solutions as well as conceptual analysis in the construction process and it relies on the application of an integrated CAD/CAE/CAM systems (Fig. 1).

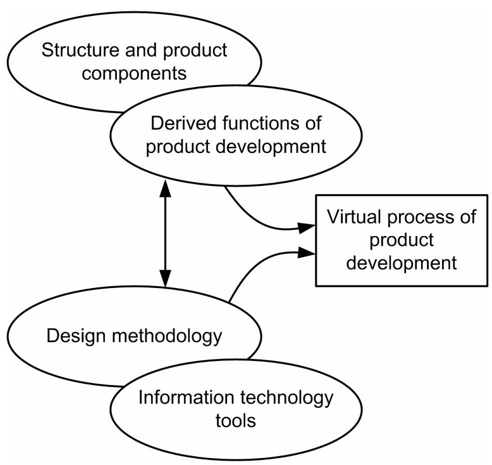

Figure 2. Generation of production orientated product development process.

The process of virtual product development has several advantages in regard to classical design logic. The aim of computer aided product oriented development is to integrate the derived product management functions with information technology tolls and design methodology into virtual product development (Fig. 2).

2. Development of Venturi Pump

Very good example about advantages of virtual product development is development of products which function relies on a Venturi effect, such as Venturi pumps shown on Fig. 3 (Venturi injectors or aspirators). Venturi pump consist of a converging-diverging nozzle to convert the pressure energy of a motive fluid to velocity energy which creates a low pressure zone that draws in and entrains a suction fluid. After passing through the throat of the injector, the mixed fluid expands and the velocity is reduced which results in recompressing the mixed fluids by converting velocity energy back into pressure energy. The motive fluid may be a liquid, steam or any other gas. The entrained suction fluid may be a gas, a liquid, a slurry, or a dust-laden gas stream [6].

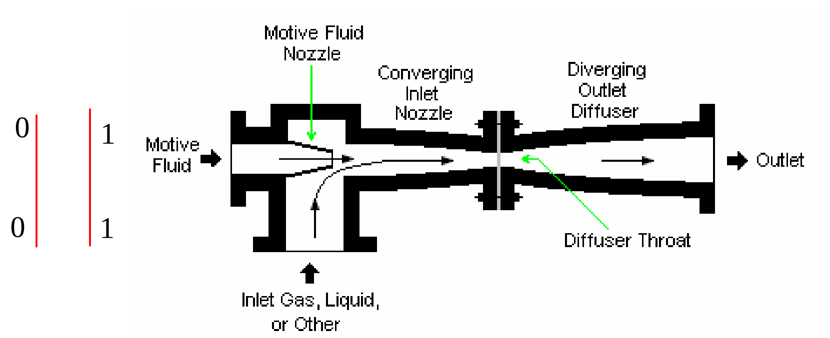

Figure 3. Operational principle of a Venturi pump.

A number of authors analyzed and performed experimental research on performance of a Venturi pump, such as discharge, suction capacity, preasure at throat, outlet velocity, etc. Up to appearance of modern computer aided tools, the development of those products relied only on previous experience of the designer, literature recommendations and trial and error procedure. Such approach was inefficient, expensive and time consuming because it required iterative procedure combined with excessive experimental testing to achieve desired properties.

The first step in the virtual development process is to define the initial geometry of the product based on preliminary calculation of the nozzle diameter.

The preliminary nozzle diameter was calculated based on Bernoulli principle and continuity law:

$$\frac{v_0^2}{2g} + \frac{p_0}{\gamma} = \frac{v_1^2}{2g} + \frac{p_1}{\gamma} \tag{1}$$

$$v_0 \frac{D^2\pi}{4} = v_1 \frac{d^2\pi}{4} \tag{2}$$

By transformation of the equations (1) and (2), one should obtain:

$$\frac{v_0^2}{2g}\left(\frac{D^4}{d^4} - 1\right) = \frac{p_0 - p_1}{\gamma} \tag{3}$$

From equation (3) it is possible to obtain the value of the nozzle throat diameter for given values of inlet diameter (D), inlet velocity (v_0) and pressures in sections 1 and 2:

$$d = D\sqrt[4]{\frac{\gamma \cdot v_0^2}{\gamma \cdot v_0^2 + 2g\left(p_0 - p_1\right)}} \tag{4}$$

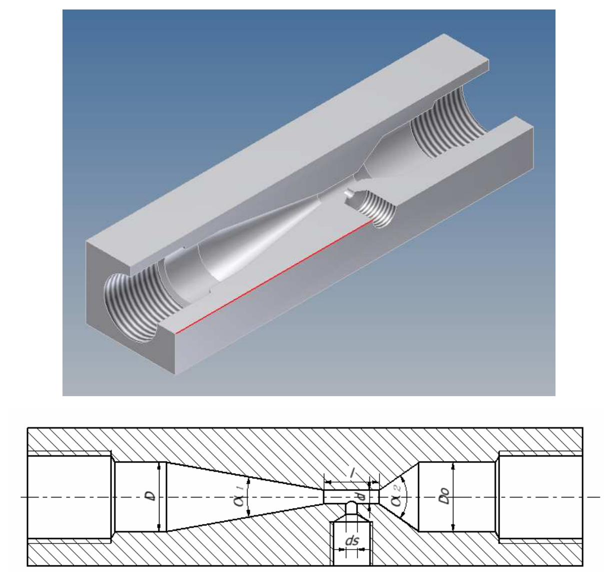

Figure 4. 3D model and draft drawing of the initial geometry.

Other geometrical dimensions were adopted according to the standard ASME MFC-3M-1985 which gives the recommendations for the selection of geometrical measures of Venturi flow meters.

Three-dimensional computer model and a draft drawing of initial geometry are shown on Fig. 4. The computer model of the product was defined trough feature based design and in later development phases, through various computer-aided product development techniques, analyzed so that it becomes a virtual prototype. Features help computer-based elaboration of the designing task.

The information which they contain is used in all phases of product development, so they represent the basis for a methodological approach to product development. Through feature-related semantics, information, rules and functional dependencies can be processed and stored in a computer, so that they can be used in the later development of the system. The dimensions of the virtual model were parameterised in order to facilitate the model change, automate the production of the design documentation and enable the parametric optimisation.

The operational behaviour of a Venturi pump can be predicted by simulation using the CFD. For the simulation purpose, the adopted initial pump design was automatically transformed into a discretised model of finite elements by applying the tools for creation of fluid region and generation of CFD mesh. The flow in the Venturi pump obtained via the CFD simulation is shown on Fig. 5.

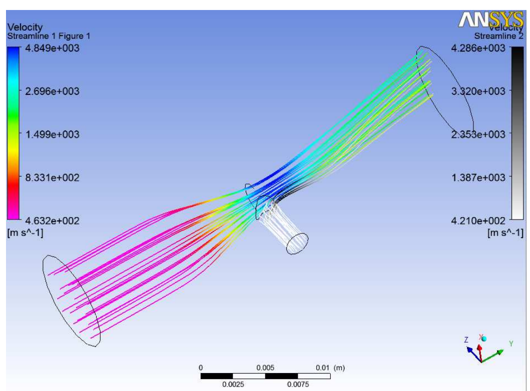

Figure 5. CDF obtained flow in the Venturi pump.

To reduce time and costs in the development of Venturi pumps, while maintaining a high product quality, it is essential to use efficient optimization tools besides the already performed CFD analysis.

The optimization procedure was performed in order to improve the design of the pump regarding its maximum suction pressure. The optimization was performed by defining the design of experiment as a central composite design in simulation. By variation of the nozzle angle ($\alpha_1 \equiv$ DSu), the diffuser angle ($\alpha_2 \equiv$ DSi), the nozzle throat diameter ($d \equiv$ DSd), the nozzle throat length ($l \equiv$ DSl) and the inlet diameter ($D \equiv$ DSDs), the functional dependence of suction capacity

(Flow T) and suction pressure (Pressure T) from input parameters was obtained. Maximisation of the obtained functional dependence regarding the suction flow or minimisation regarding the suction pressure results in some of the optimal geometric dimensions of the Venturi pump. The functional dependence of suction pressure from input parameters are shown in Fig. 6 to Fig. 8.

It is clear from the Fig. 6 - 8 that suction pressure drops with decrease of α_1, α_2 and d or increase of l and D.

With the proper selection of geometric parameters the suction pressure can be reduced up to two times for the same value of nozzle diameter (d).

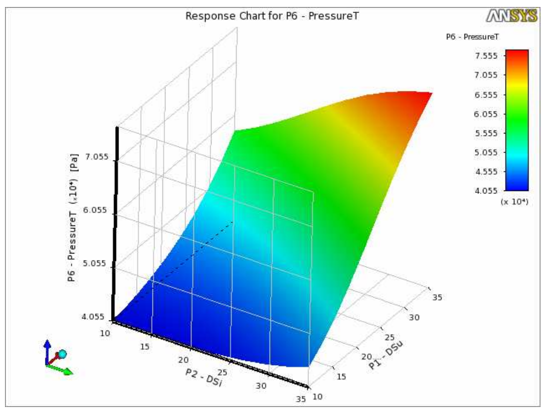

Figure 6. Functional dependence of suction flow from input parameters α_1 and α_2 (d, D, l = const.).

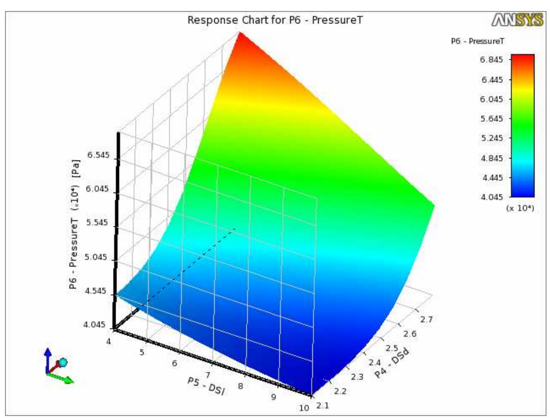

Figure 7. Functional dependence of suction flow from input parameters d and l (α_1, α_2, D = const.).

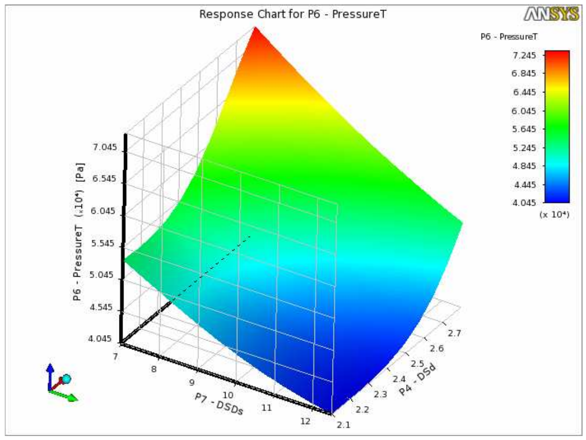

Figure 8. Functional dependence of suction flow from input parameters d and D (α_1, α_2, l = const.).

The sensitivity of the output parameters from the optimisation parameters is given on Fig. 9. It is clear from the Fig.9 that the largest influence on suction pressure has the input parameter α_1. Values of nozzle diameter (d) and inlet diameter (D) have also significant influence on the value of the suction pressure.

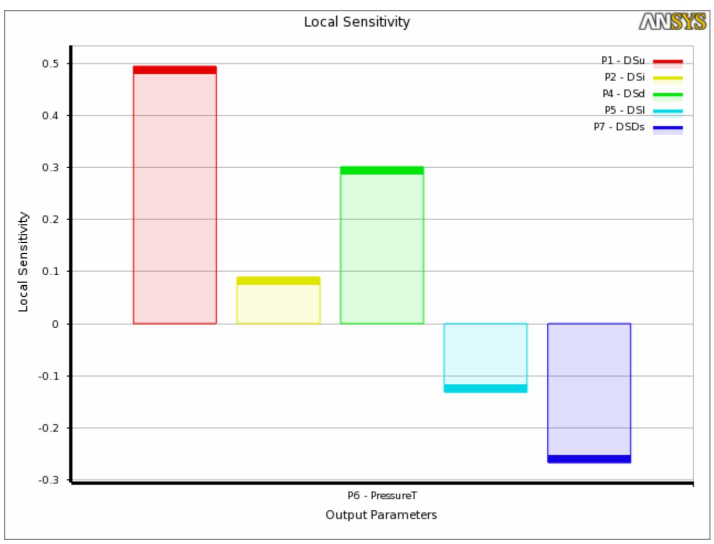

Figure 9. Sensitiveness of suction pressure to the optimisation parameters.

Fig. 10 shows the Pareto front of feasible points for the two most influential input parameters, d and α_1. It is obvious from the noted picture that there are numerous possible combinations of input design parameters.

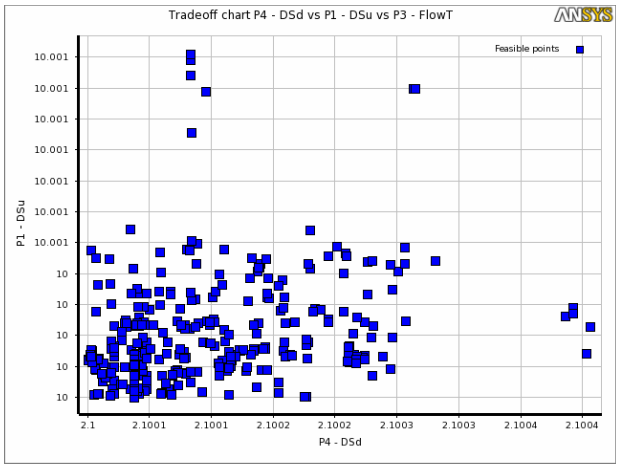

Figure 10. Pareto front of feasible design parameters d and α_1.

Based on optimisation procedure, the combination of geometric parameters was adopted based on desired value of suction pressure. The flow in the adopted design candidate is shown on Fig.11.

Based on the optimisation procedure it can be concluded that the recommendations of the ASME MFC-3M-1985 standard are not adequate for design of Venturi pumps.

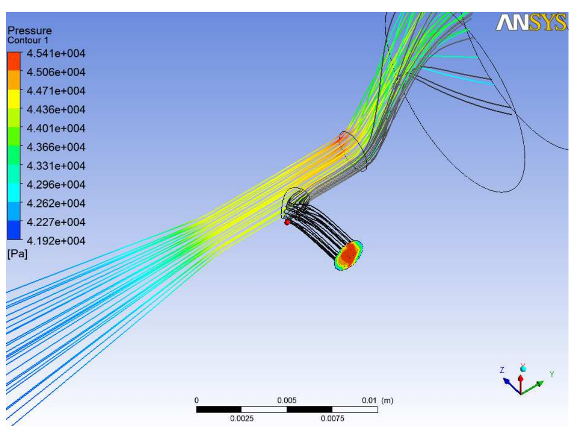

Figure 11. Flow in the adopted design candidate

Previously generated feature based geometry enables the automatic generation of code for numerically controlled machine tools. Noted production procedure reduce time and cost related to phase of product transfer to production.

The described procedure of virtual development of Venturi pump drastically reduces time and costs related to its development as well as improve the product operational performance and thus enable innovation and enterprise competitive.

3. Conclusion

Based on stated above, the following conclusions can be drawn:

1. The concept of virtual product development enables the development and optimization of novel designs and, consequently, reduces the costs and the time to market.
2. Virtual product development enables the sharing of product related data by everyone in the product development process right at the outset.
3. Virtual product development improves product innovation through the iterative design process as well as the product quality by using the digital validation, mapped to product requirements and test plans.
4. Very good example of virtual product development is a development of Venturi pumps. As their development process requires extensive iterative procedure integrated with physical testing, the virtual development greatly decreases the number of required tests and thus lowers the time and costs related to development of these products. The ability to perform unlimited virtual testing, which depends solely on available computer resources, gives designer a better control over physical and mechanical properties of these products and improves their quality.

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