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EXPERIMENTÁLNÍ A NUMERICKÉ ŘEŠENÍ VZNIKU A VÝVOJE KAVITACE V LAVALOVÉ DÝZE

EXPERIMENTAL AND NUMERICAL SOLUTION OF FORMATION AND EVOLUTION OF CAVITATION IN LAVAL NOZZLE

Abstrakt

Příspěvek prezentuje experimentální zařízení ke vzniku a vývoje kavitace v Lavalově dýze. Podrobně je charakterizována stavba zařízení včetně navrženého měření základních fyzikálních veličin tlaku a průtoku. Oblast vzniku a vývoje kavitace pro různé provozní parametry je vyhodnocena pomocí digitálních snímků. V druhé části je definován vícefázový matematický model kavitace v programovém prostředí ANSYS Fluent12. Model kavitace je následně aplikován na výpočetní oblast Lavalovy dýzy za stejných okrajových podmínek jak u experimentu. Výsledky numerické simulace jsou konfrontovány s experimentálním měřením. Dále je návrh experimentálního zařízení rozšířen o návrh sycení kapaliny vzduchem včetně průtokoměru k stanovení množství syceného vzduchu.

Abstract

Contribution presents experimental equipment applied for formation and evolution of cavitation in Laval nozzle. In detail the equipment design including nominated measurement of basic physical quantities as pressure and flow rate is described. The region of cavitation formation and evolution for various operating conditions is evaluated using digital exposure series. In the second part of paper the multiphase mathematical model of cavitation in program ANSYS Fluent12 is defined and applied for computational region of Laval nozzle using the same boundary condition as in experiment. Results of numerical simulation are compared with experimental measurement. Furthermore the design of experimental equipment is extended in air saturation design of water including flowmeter design for determination of saturated air amount.

1 INTRODUCTION

Cavitation and cavitation fade in hydraulic systems is significant and actual problem. This phenomenon of cavitation cavity detection is connected with thermodynamic diffusion in microscopic regions of fluid flow and is characterized by small time changes. Existing cavitation

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causes noisiness of the whole equipment and material fade and therefore is investigated theoretically and experimentally with respect to the correct designing, construction and operation of hydraulic mechanisms. The works focused on numerical and experimental investigation of cavitation in hydraulic elements (Venturi tube, diffusor with rectangular cross-section, etc.) are cavitation arises in fluid position, where the pressure and temperature has the special value. If the pressure drops under the value of saturated pressure by operating temperature, then the small vapor bubble occurs and the fluid consistency is broken. If the pressure value is going down permanently, the bubble is gradually enlarged. In the flowing liquid the bubble is drifted in position with higher pressure then the saturated pressure and this vapor bubble implodes [4]. When this implosion is located near the walls or on the walls for the certain time, then the material surface is damaged. This phenomenon is called cavitation erosion.

2 EXPERIMENTAL EQUIPMENT FOR VISUALISATION OV CAVITATION

Experimental measurement circuit (Fig. 1) consist from pump (HG) driven by electromotor with revolutions controlled by frequency converter and subsequently water flow rate in interval of Q_V ($0{,}00213 m^3 \cdot s^{-1} \div 0{,}00337\ m^3 \cdot s^{-1}$). Behind the pump there is placed the induction flowmeter (IP), which is connected through the data converter TB 650 by firm Humusoft into the computer. Then there follows Laval nozzle (LD) subserving to formation and visualization of cavitation. In the measuring hydraulic circuit there are other elements as pressure sensors placed in various positions in the circuit. Hydraulic elements are connected by PVC flexible pipe. All output analog signals are transformed using analog-digital converter into computer, where software Matlab-Simulink is dispose for pressure and flow rate evaluation. In Fig. 2 the hydraulic scheme of experimental measuring circuit is shown.

Technical parameters of hydraulic elements were proposed on executed numerical simulation base using program Ansys Fluent 12.1. At first the plexi model of Laval nozzle was made out. Then by testing boundary condition in numerical simulation of the cavitation flow the input pressure and flow rate values at inlet into Laval nozzle were defined. Pump and others hydraulic elements were suggested on so determined parameters.

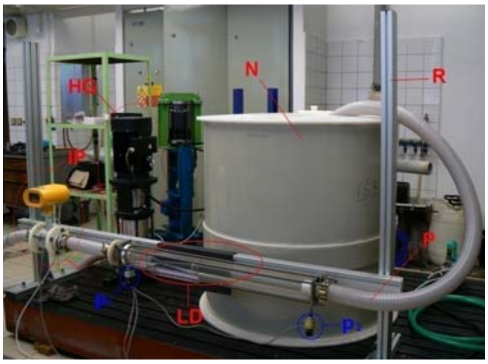

Fig. 1 Experimental equipment for cavitation evaluation

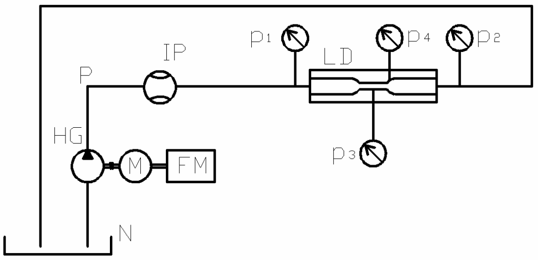

Fig. 2 Hydraulic scheme of experimental equipment .

Selected element of experimental measuring equipment for cavitation evaluation was Laval nozzle produced from transparent material (plexi material Tecanet) to observe incurred cavitation area. Tecanat is amorphous transparent material with superlative impuls solidity used permanently by operating temperature till 120°C. The dimensions of Laval nozzle are shown in Fig. 3.

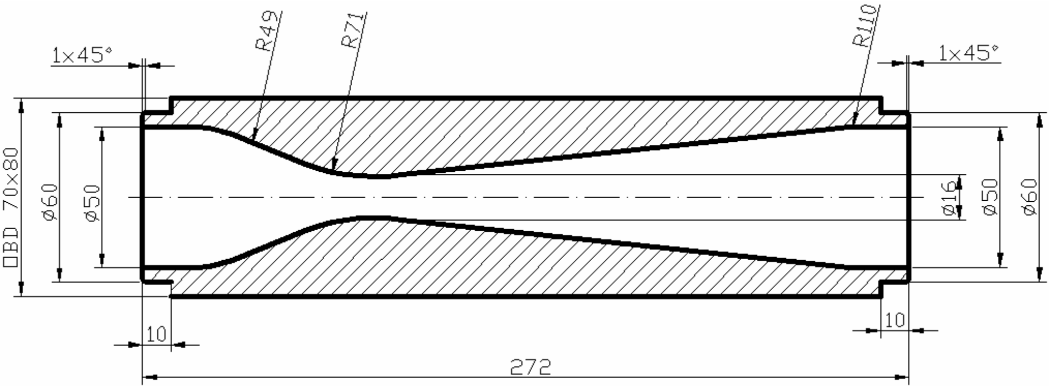

Fig. 3 Model of Laval nozzle for cavitation evaluation

Second design step was focused on the way how to measure basic physical values as pressure and flow rate. In measuring circuit there were grouped pressure sensors placed on begin, end and in contraction of Laval nozzle. Moreover the inductive flowmeter was placed in circuit. These pressure and flow rate values will be scanned into computer using analog-digital converter. Obtained results will be elaborated in graphs and tables. Pressure time serie measured in contraction part of the tube will be evaluated by method of the frequency analysis.

3 EVALUATION OF CAVITATION AREA IN LAVAL NOZZLE

Every measurement of fluid flow in the Laval nozzle is recorded by digital exposure, where the first occurrence of cavitation and other cavitation area depending on increasing pump flow rate are visualised. From Fig. 4 it is clear, that cavitation is not exist, because the pressure value in contraction of Laval nozzle das not drop to the saturation pressure. In the next Fig. 5, 6 and 7 we can observe the cavitation progress from flow rate value Q_v=0,00246 m^3s^{-1} to value Q_v=0,00337 m^3s^{-1}. Cavitation start-up is noticeable from Fig. 5 and full developed cavitation in the whole region of Laval nozzle is demonstrated in Fig. 7.

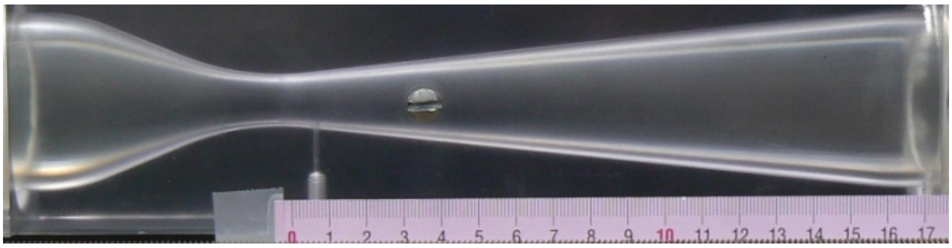

Fig. 4 Visualisation of fluid flow in Laval nozzle with flow rate Q_v=0,00213 m^3s^{-1}

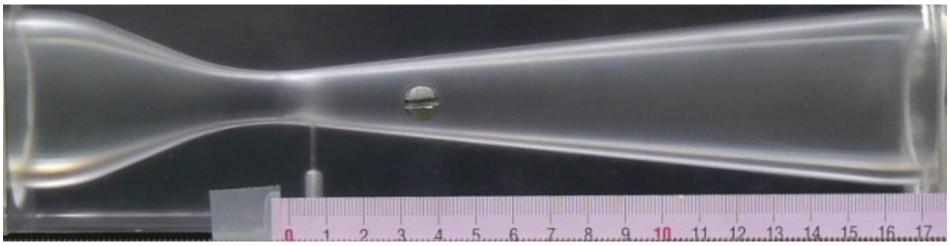

Fig. 5 Visualisation of fluid flow in Laval nozzle with flow rate Q_v=0,00246 m^3s^{-1}

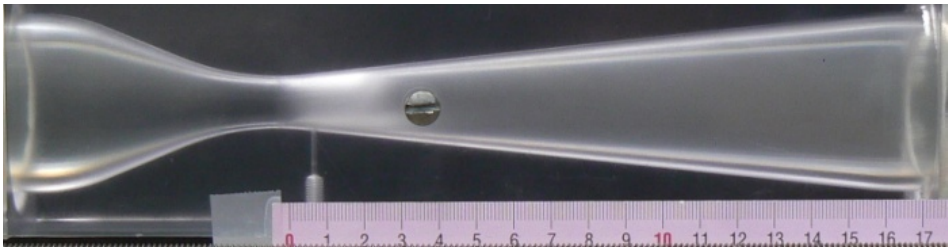

Fig. 6 Visualisation of fluid flow in Laval nozzle with flow rate Q_v=0,0028 m^3s^{-1}

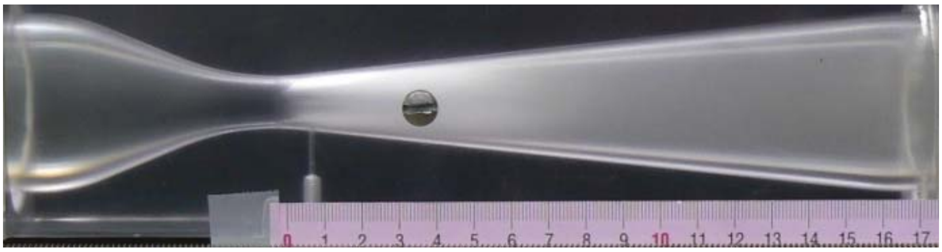

Fig. 7 Visualisation of fluid flow in Laval nozzle with flow rate Q_v=0,00337 m^3s^{-1}

4 MATHEMATICAL MODELING OF CAVITATION AREA

Mathematical model of fluid flow with cavitation [1], [2] in program ANSYS Fluent 12.1 is defined as follows:

- mathematical model of turbulent flow (RNG $k-\varepsilon$ model)
- multiphase model of mixture (water + vapor + air), concurrently water is supposed as incompressible medium and gas as compressible medium
- Singhal cavitation model, which is most complicated but preferably satisfies to experimental requirement and is numerically most stable. Other potential models in program ANSYS Fluent 12.1 are Zwart-Gerber-Belamri and Schnerr – Sauer. These models were tested too but with no fulfil results.

Physical properties constituent phases were defined for water, vapor and air, see Tab.1.

Tab. 1 Physical properties of phases

Physical properties	**water**	**vapor**	**air**
Saturation pressure [Pa]	2368,7		0
Surface stress [N.m^{-1}]	0,0717		
Density [kg.m^{-3}]	1000	ideal gas	defined by user
Viscosity [Pa.s]	0,000985	$8{,}854.10^{-6}$	$1{,}789.10^{-5}$

Next step is focused on definition of corresponding boundary conditions [3] at inlet and outlet in Laval nozzle, which were determined for all variants in accordance with experimental measurement. Due to clearness there are in Tab. 2 shown boundary conditions for flow rate of water Q_V = 0.003 $m^3.s^{-1}$. In the same table boundary condition for vapor and air are defined too.

Tab. 2 Boundary conditions at inlet and outlet if Laval nozzle

	water	vapor	air
Mass flow at inlet [kg.s^{-1}]	3	0	1,902.10^{-6}
Absolut pressure at outlet [kPa]	105		
mass fraction of noncondesable gas at inlet[1]			1,5.10^{-8}

In the same way boundary conditions for other variants were defined using experimental measurements. Results for this variant are in good agreement with measured values of pressure and dimension of cavitation area, see Fig. 8 and Fig. 9.

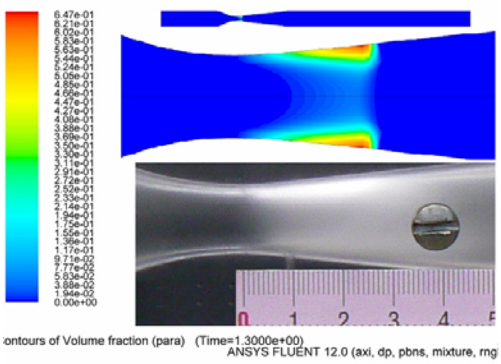

Fig. 8 Visualisation of vapor area in nozzle contraction (volume fraction of vapor)

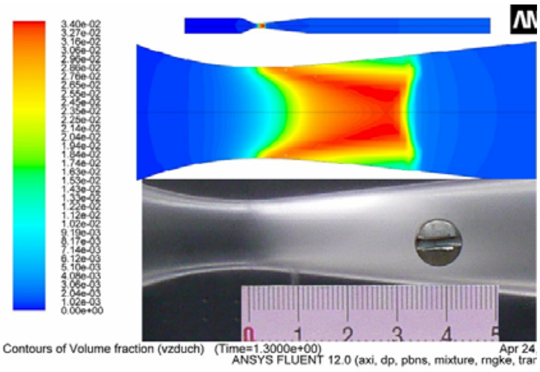

Fig. 9 Visualisation of air area in nozzle contraction (volume fraction of air)

5 CONCLUSION

Contribution deals with experimental and mathematical modeling of formation and evolution of cavitation in simple hydraulic element (Laval nozzle) where the flowing medium is water. It is evident, that fluid flow modeling and acquisition of parameters from simulation is important in practical application of results. In this way gained results are at disposal in shorter time, then those one gained from experimental equipment (at first designed, than produced and put together). Moreover very simply it is possible to change geometry and numerically simulate flow in new geometry and gain new variant of results. To the contrary new geometry in physical experiment requires production of new hydraulic element.

It is possibly to notice, that physical experiment will be specified to accurate air content measurement, air saturation of water and investigation of periodical behaviour of cavitation area in contraction primarily in case of lower air content value. From point of numerical modeling will be needful to specify mathematical model using Euler approach, for visualization to use new elements and FFT method frequency analysis of periodical flow in cavitation area.

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