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UNSTEADY PRESSURE MEASUREMENTS IN CONICAL DIFFUSER WITH SWIRLING FLOW

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ABSTRACT

The paper presents an experimental investigation of pressure fluctuations in conical diffuser with swirling flow. One of the main issues in draft tube cone of Francis turbine is the swirling flow and vortex rope when the turbines with fixed blades operate at partial load. To investigate the problem we design and built an experimental test rig. Also to control the swirling flow and the vortex rope is use a new method: injection of the water in draft tube. The measurements were made with two pressure transducers in order to analyse the behaviour of pressure fluctuations when we don’t have injection of the water and when an axial water jet is injected. Also is presented an analysis of the measurement for different jet discharge.

KEYWORDS

Conical diffuser, swirling flow, water jet control, pressure measurements

NOMENCLATURE

$$c_p = \frac{(p_2 + \rho g z_2) - (p_1 + \rho g z_2)}{\frac{\rho v_0^2}{2}}$$ [-] pressure recovery coefficient

$$v_0 = \frac{4 \times \left(Q_{jet} + Q_{funct}\right)}{\pi \times D_{throat}^2}$$ [m/s] velocity at the inlet of the conical diffuser

$\sqrt{\overline{\left(p^{'}\right)^2}}$ [-] root-mean-square (rms) amplitude of pressure fluctuation

$$c_{p\,RMS} = \frac{\sqrt{\overline{\left(p^{'}\right)^2}}}{\frac{\rho v_0^2}{2}}$$ [-] pressure parameter

$c_m = \sqrt{(c_r)^2 + (c_z)^2}$ [-] meridian velocity coefficient

p	[Pa]	pressure
ρ	[kg/m^3]	density
z	[m]	level from the tank to the transducers
Q_{jet}	[m^3/sec]	volumic flow rate from auxiliary circuit
Q_{funct}	[m^3/sec]	volumic flow rate from main circuit
D_{throat}	[m]	minimum diameter of the test section

ABBREVIATIONS

S1	upstream section
S2	downstream section
M1, M2, M3, M4	number of measurements

1. INTRODUCTION

In our days the variable demand of the energy requires a great flexibility in operating hydraulic turbines. So turbines operate over an extended range of regimes far from the best efficiency point. When a turbine operates at partial discharge downstream of runner especially in Francis runner appear a decelerated swirling flow. From decelerated swirling flow result a vortex with a precision motion or so called vortex rope. All the time the vortex rope leads to severe pressure fluctuation that produces damage of the runner or breakdown of the runner blades.

Two methods are developed in order to investigate the swirling flow with vortex rope precession:

numerical simulation and experimental investigations.

For experimental measurements are used pressure fluctuations measurements. With pressure fluctuations are investigated the amplitudes and frequency witch indicates their relationship to the precession of the vortex rope in draft tubes [14].

Vevke [12] presents a study of the flow in hydro turbines with different runner cone configurations, operating in the part bad operating range. Dynamic wall pressure measurements on a model Francis pump-turbine and two prototype Francis turbines have been performed. A semi tapered cone was attached to the hub of the runner for then of the runner cone configuration, while the eleventh being the original runner cone configuration. The results indicate that the attached devices have a damping effect on the pressure fluctuations in the draft tubes cone for high part bad operation, compared to the original runner cone. His advice is a cone with variable length for different points of operation.

Arpe [1] analyse the pressure fluctuations in draft tube of Francis Turbine for three operating points at partial load. From the influence of vortex volume vapours are produce the pressure fluctuations near the wall and the velocity of the vortex varied.

Kirschner [3] investigate the swirling flow in a simplified straight draft tube. To investigate the vortex rope movement the vortex core was visualized by air. Additionally the pressure recovery of the draft tube and the unsteady pressure at the draft tube wall was measured. Operating points with different discharge and swirl-angle of the flow at the draft tube inlet were investigated experimentally in order to show the necessary discharge of the injected water for different boundary conditions.

In laboratory the swirling flow in conical diffusers was generated by adjustable guide vanes, by fixed vanes, or by tangential inflow through a long split. The closest setup to the hydraulic turbine case seems to be the adjustable radial guide vane apparatus which has been largely used [4].

To reduce the swirling flow and control the pressure fluctuations in draft tubes of Francis runners are used different methods such: stabilizer fins, co-axial cylinders or special aerators [11].

Nishi [6] use to eliminate the swirling flow a vortex generator jet that is a pitched and skewed jet which issues from a small hole into a flow over a solid wall. The jet generates a single streamwise vortex which remains close to the wall, and extends many jet hole diameters downstream. The method suppresses separation in a conical diffuser and improve the pressure recovery but is difficult to mount in practical implementation.

Kurokawa [5] introduce the so called J-groove method, and use shallow grooves machined on a casing wall. The results showed that J-groove is effective to suppress swirl, but it makes the back flow region larger in the center, because J-groove is mounted along the wall and effective to drop the near wall swirl-velocity.

All these methods produce other instabilities in draft tubes cones and reduce the effect but not eliminate the cause and drop the efficiency.

A new method simple and robust propose by Resiga [7][8][9][10] to mitigate the vortex rope is investigate: a water jet issued from the crown type of the runner. The main advantages of the method are: mitigate the pressure fluctuations and the vortex rope, is adjustable according to the operating point and is simple and robust for practical implementation.

2. TEST RIG AND SWIRL GENERATOR DEPELOPED AT “POLITEHNICA” UNIVERSITY OF TIMISOARA

To investigate the swirling flow in conical diffusers and to analyse the new method with injection of the water it was design and built an experimental test rig presented in Fig. 1.

The main circuit is use to supplying with water the test section. It has a lower reservoir ($4m^3$) from stainless steel, a main centrifugal pump with variable speed with 0-35*l/sec* volumic flow rate, two ball valves downstream and upstream of the pump, an electromagnetic flow meter with 0.2*%* accuracy. The upper reservoir provides a well controlled uniform flow thought ø150*mm* pipe to the test section.

The auxiliary circuit supplies with water the jet. The auxiliary pump with variable speed extract water from the main reservoir between 0-4*l/sec*, the volumic flow rate is measured with a turbine flow meter of 0.05*%* accuracy. To control the small volumic flow rates is use a ball valve mount in auxiliary circuit witch has ø35*mm* diameter.

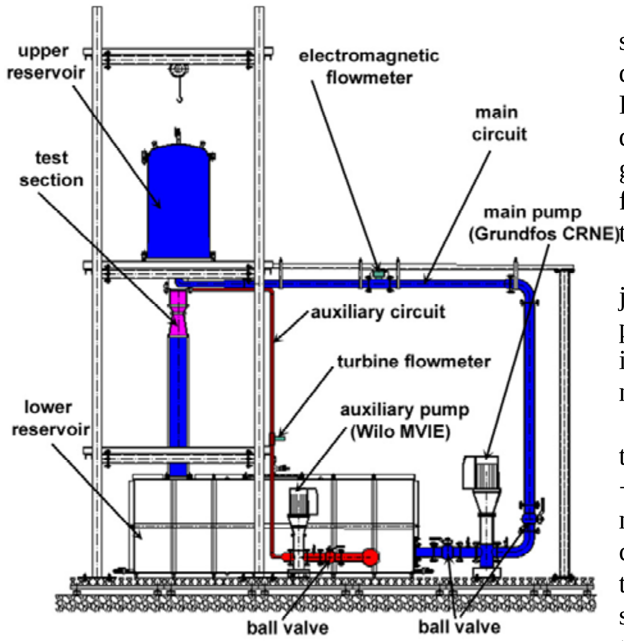

Fig. 1. Closed loop test rig for experimental investigations of swirling flows

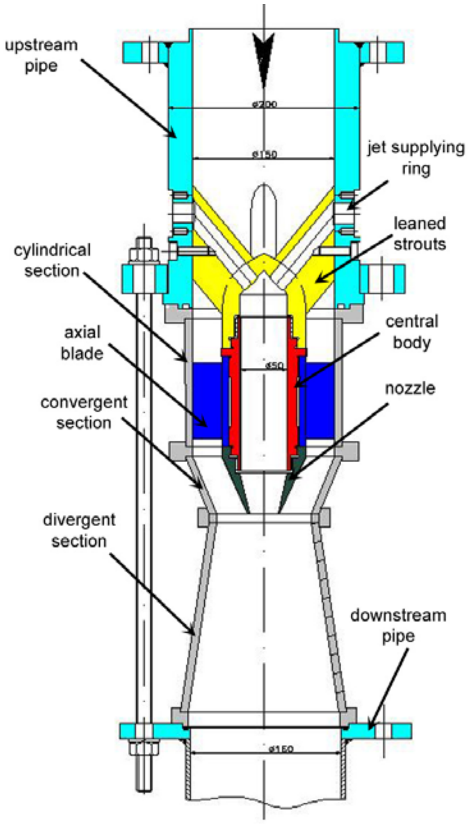

Fig. 2. Swirl generator with test section from Plexiglas

The main part of the test rig is the swirl generator shown in Fig. 2. It has provided a swirling flow in divergent section like swirl from the draft tube of Francis turbine. For this condition we design and develop a swirl generator with fixed blades that generate at the inlet of divergent section a swirling flow corresponding to the outlet of the Francis turbine runner.

The water from auxiliary circuit is collected by a jet supplying ring. After leaned strouts the water pass into a central body with ø50*mm* diameter and is injected at the inlet of the divergent section with a nozzle which has ø30*mm* diameter.

Because is a closed loop test rig, we can adjust the pressure inside from the installation between +0.5÷-0.5bar. Adjusting the pressure the measurements were made with cavitation or without cavitation. On the other hand is possible to control the flow rate with main pump which has a variable speed. From this is easy to control the intensity of the swirl and vortex rope from the test section.

3. EXPERIMENTAL MEASUREMENTS

For experimental measurements two unsteady pressure transducers were installed on the divergent section, one near at the inlet at 30*mm* from the throat and another near at the outlet with 150mm distance between them (see Fig. 3). We use a Cole-Palmer transducer with a range of ±1bar with a precision of 0, 13*%*. The sampling frequency was 512Hz and 256Hz with samples recorded to 16 seconds. In analysed measurements we use a frequency of 512Hz in order to catch al the frequency. In Fig. 4. are shown the transducers already flash mounted on the divergent section and connected to the acquisition system. The acquisition system is specially design for test rig, in order to record 8 signals from pressure transducers.

In measurements the test rig was use without cavitation, we maintain Q_{funct} constant and Q_{jet} it was modified by changing the speed of the secondary pump.

4. PRESSURE FLUCTUATIONS ANALYSIS

In Fig. 5 are shown the pressure fluctuations for the case without jet (black) and with jet (green). Pressure recovery when the water is injected (with $10\%Q_{jet}/Q_{funct}$) is observed only for S1.

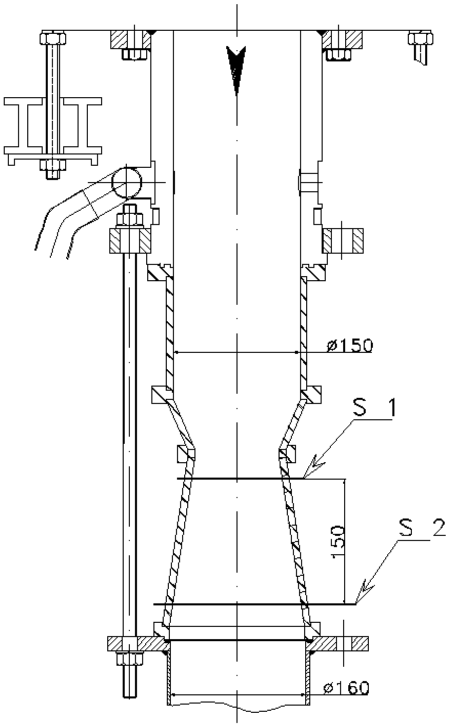

Fig. 3. Schetch of the test section with two sections for measurement

Fig. 4. Pressure transducers already mounted on the test section

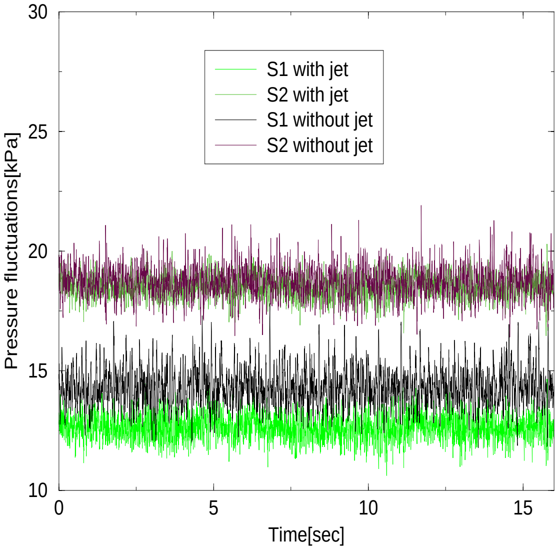

Fig. 5. Example of pressure fluctuations without jet and with jet for 10% discharge

In the next figures (Fig. 6 to Fig. 13) are shown Fourier transformations of the pressure fluctuations. The value for frequency of the vortex rope in the case without jet is 8Hz with 0.14kPa amplitude (Fig. 6). When the water is injected frequencies and amplitudes decrease. In Fig. 13 when discharge of the jet has 13% from Q_{funct} the frequency of the vortex rope has 5Hz and the amplitude has a value of 0.03kPa. As a result the pressure fluctuations when the water is injected are smaller that in the case without jet.

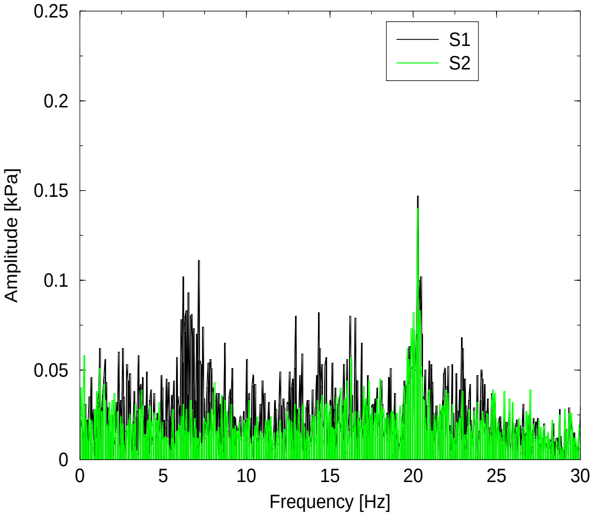

Fig. 6. Fourier transforms of pressure fluctuations without jet

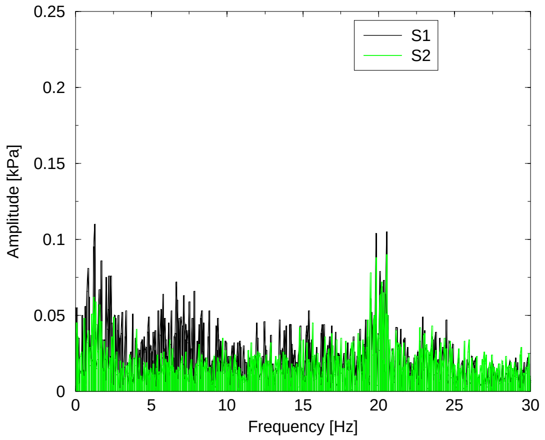

Fig. 7. Fourier transforms of pressure fluctuations with 1, 5% Q_{jet}/Q_{funt}

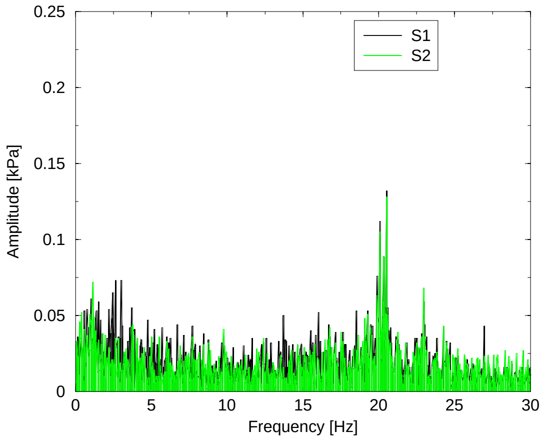

Fig. 8. Fourier transforms of pressure fluctuations with 3% Q_{jet}/Q_{funt}

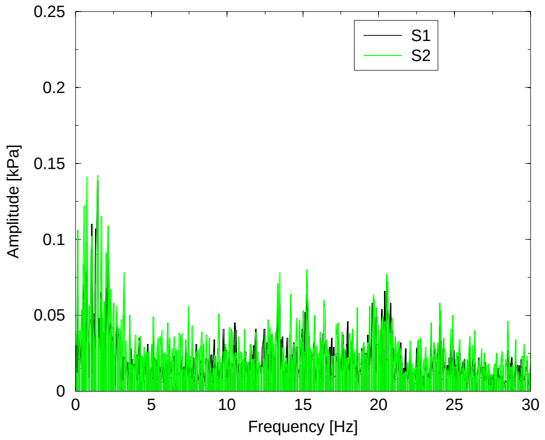

Fig. 9. Fourier transforms of pressure fluctuations with 5% Q_{jet}/Q_{funt}

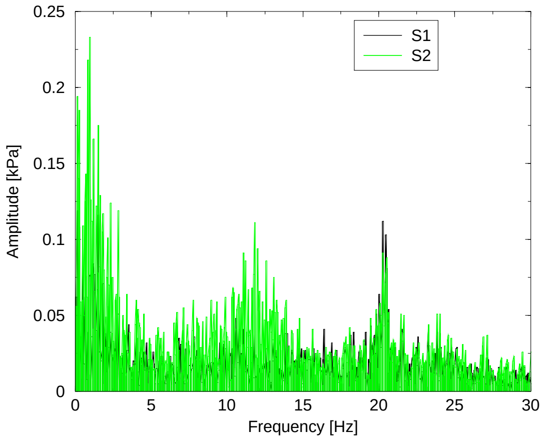

Fig. 10. Fourier transforms of pressure fluctuations with 7% Q_{jet}/Q_{funt}

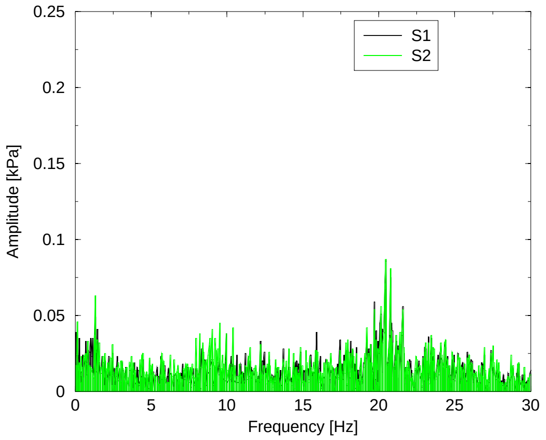

Fig. 11. Fourier transforms of pressure fluctuations with 8.5% Q_{jet}/Q_{funt}

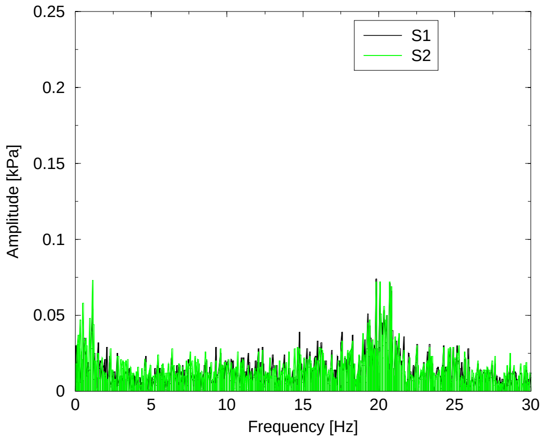

Fig. 12. Fourier transforms of pressure fluctuations with 10% Q_{jet}/Q_{funt}

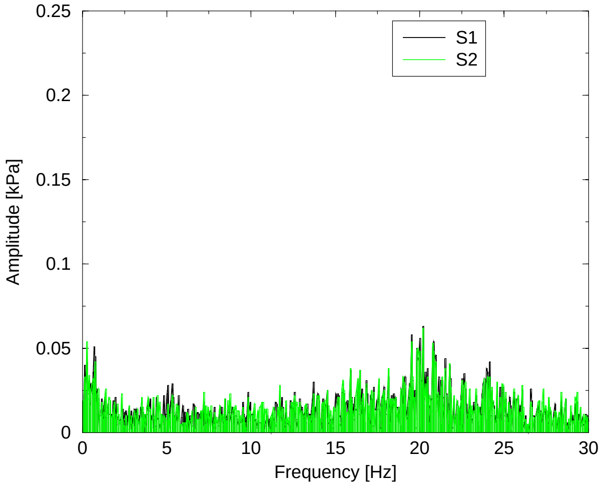

Fig. 13. Fourier transforms of pressure fluctuations with 13% Q_{jet}/Q_{funt}

When Q_{jet} is zero c_p has a value of 0, 43 after when is injected the water it drop because of the instability induced by jet. After a increase of the flow rate for jet, c_p starting to increase and when the flow rate of the jet is more then 10% from the Q_{funct} , c_p became stable at a value of 0,47.

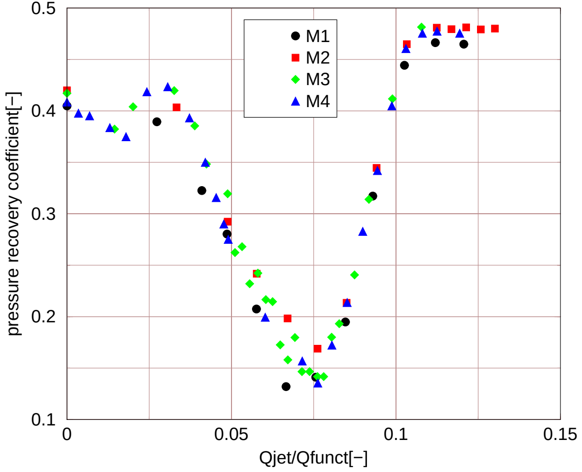

Fig. 14. Pressure recovery coefficient at various flow rates of the jet

To observe the phenomenon from pressure fluctuations is introduce a pressure parameter [13]. For S1 , c_{pRMS} has a decreasing curvature witch is normally and is saw in figures for Fourier transforms where amplitudes and frequencies are smaller when the jet is injected as is show in Fig. 15.

In order to analyze the pressure recovery parameter with pressure parameter is shown Fig. 16 where is described the variation in percent.

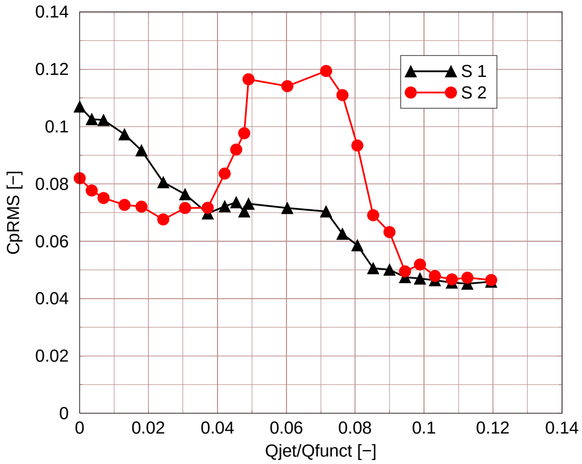

Fig. 15. Pressure parameter at various flow rates of the jet

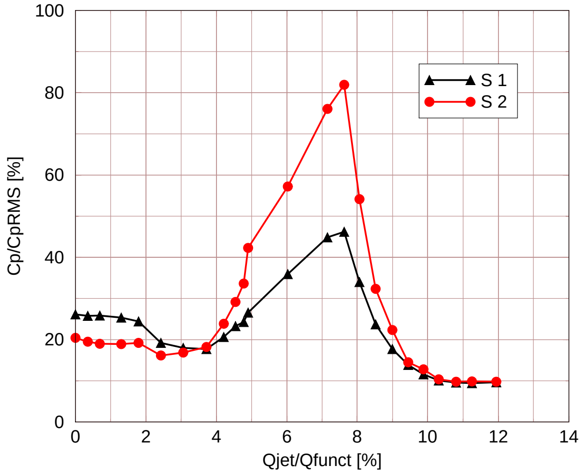

Fig. 16. Pressure recovery coefficient vs. pressure parameter

In order to identify the amplitudes of pressure fluctuations and frequencies for each zone from the graphic for pressure recovery coefficient is show Fig. 17. In this picture are shown the frequencies only for S1 transducer because in this area vortex rope exists. At first the amplitudes have large values (0.15kPa) and after the jet of water is injected the amplitudes decrease and reach a value of 0.4kPa when the jet has 10% from Q_{funct}.

5. CONCLUSIONS

We made first unsteady pressure measurements for swirling flow in conical diffusers. From these we analyze the amplitudes and frequency pressure fluctuations. As a result we identified the region that corresponds to the vortex rope in case without and with jet. In Fig. 17, the pressure recovery coefficient c_p reaches the maximum value if only the jet discharge is larger than 10% from the main discharge.

Because is difficult to identify the vortex rope in the area for the second transducer we design and produce another test section and a swirl generator. In the new configuration we have two blades, one of them is with fixed blades and another (downstream from the fixed blade) is with mobile blades who will produce a larger vortex rope. On the other hand the new test section has a profiled interior in order to mitigate the sharp edges that produce the detachment of the current like in the old section.

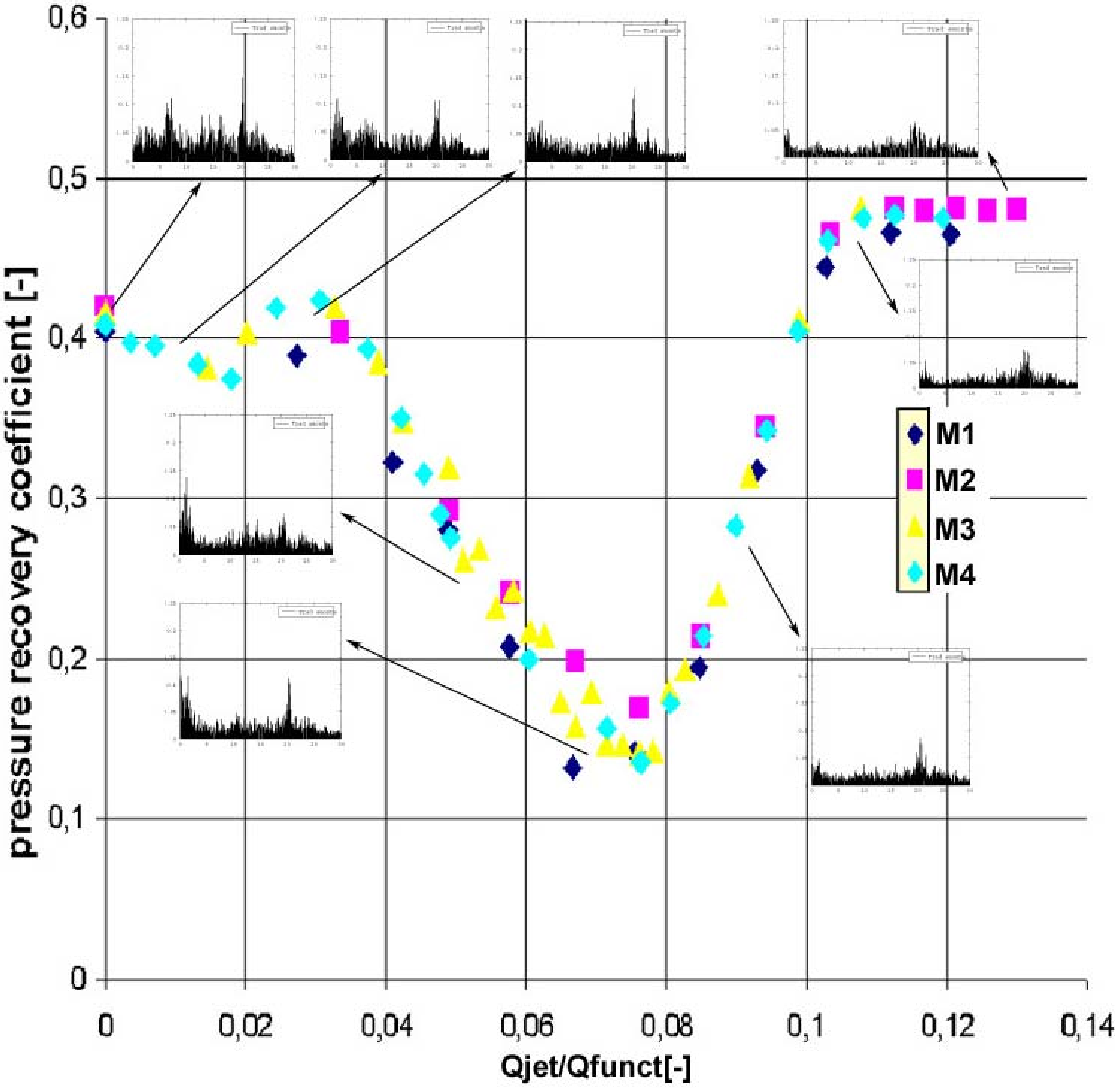

Fig. 17. Analysis of pressure fluctuations at different flow rates of the jet for pressure recovery coefficient

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